IWEC

3. International World Energy Conference

FULL TEXTS BOOK

EDITORS
Mustafa Serdar GENÇ
Gamze GENÇ
Şükrü Taner AZGIN
Saltuk Buğra SELÇUKLU

ISBN: 978-625-367-567-7

INTERNATIONAL WORLD ENERGY CONFERENCE-III

December 4-5, 2023 / Kayseri, Türkiye

TÜRKİYE CUMHURİYETİ'NİN YÜZÜNCÜ YILI

FULL TEXTS BOOK

EDITORS

Prof. Dr. Mustafa Serdar GENÇ
Prof. Dr. Gamze GENÇ
Assoc Prof. Şükrü Taner AZGIN
Assist. Prof. Saltuk Buğra SELÇUKLU

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CONFERENCE ID

CONFERENCE TITLE
3. International World Energy Conference

DATE and PLACE
December 4-5, 2023 / Kayseri, Türkiye

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Oral presentation

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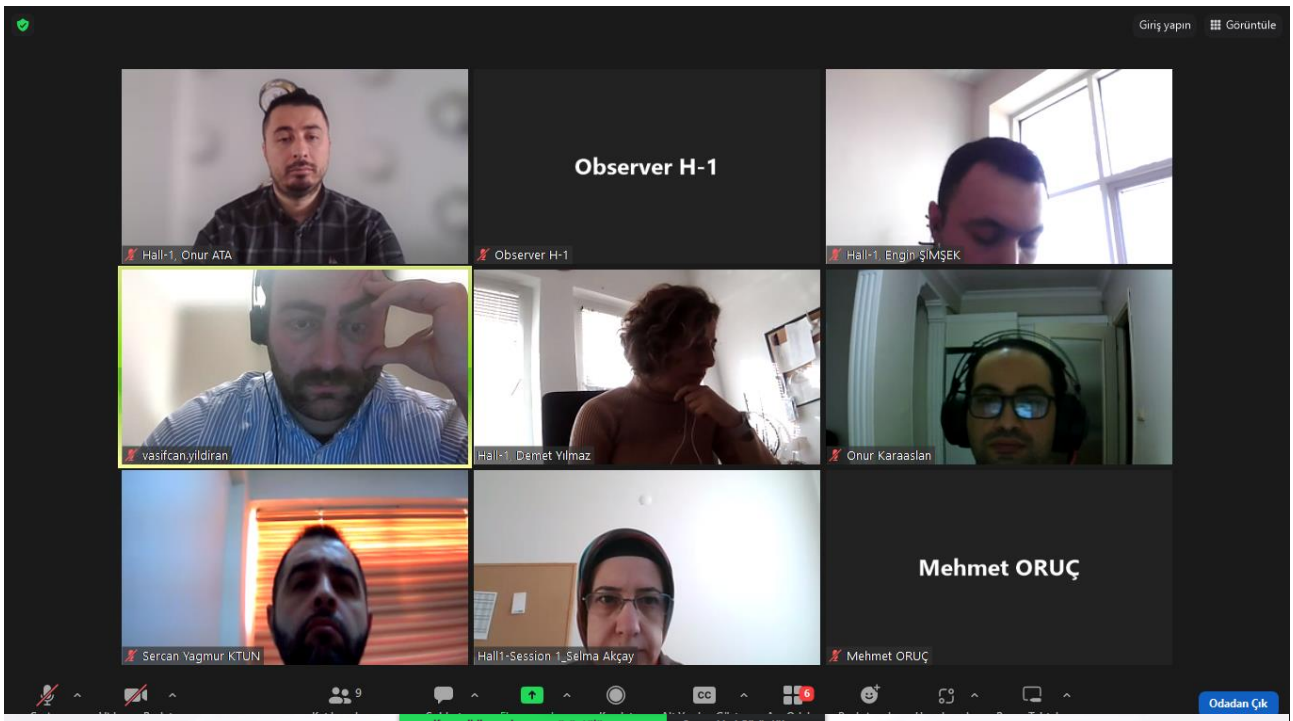
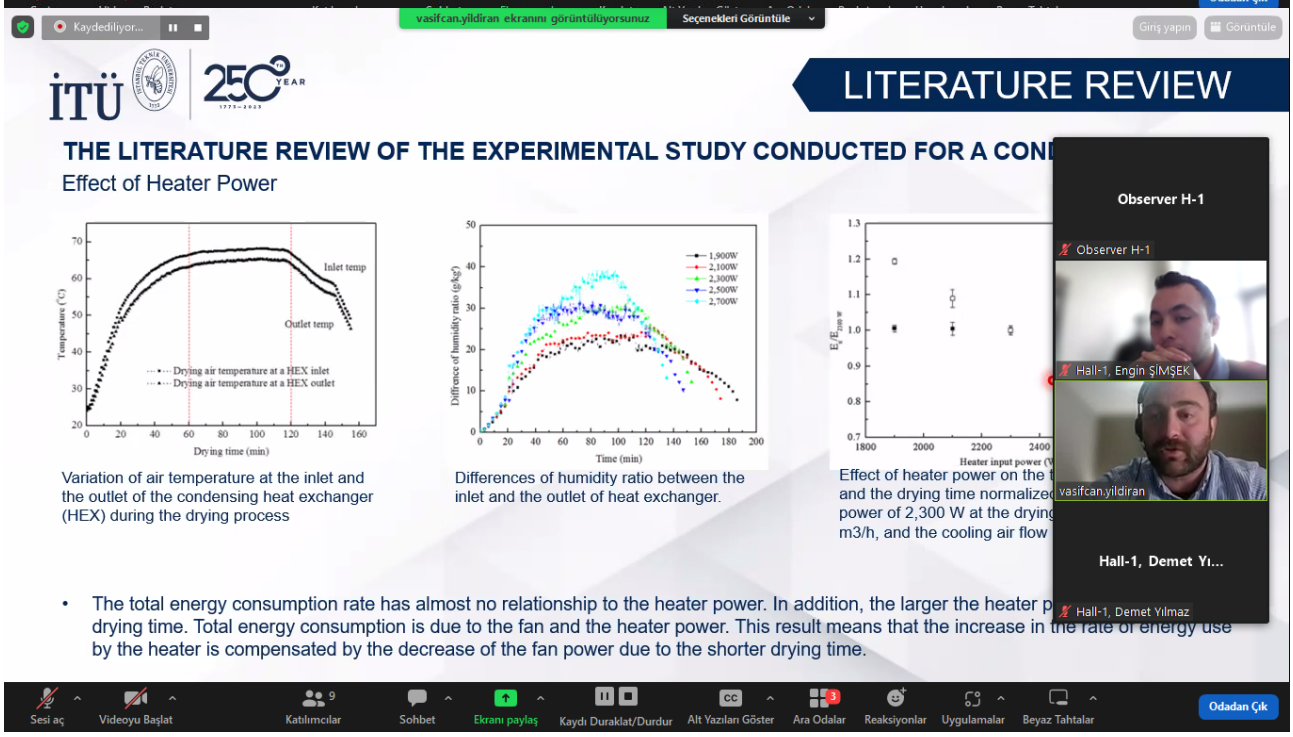
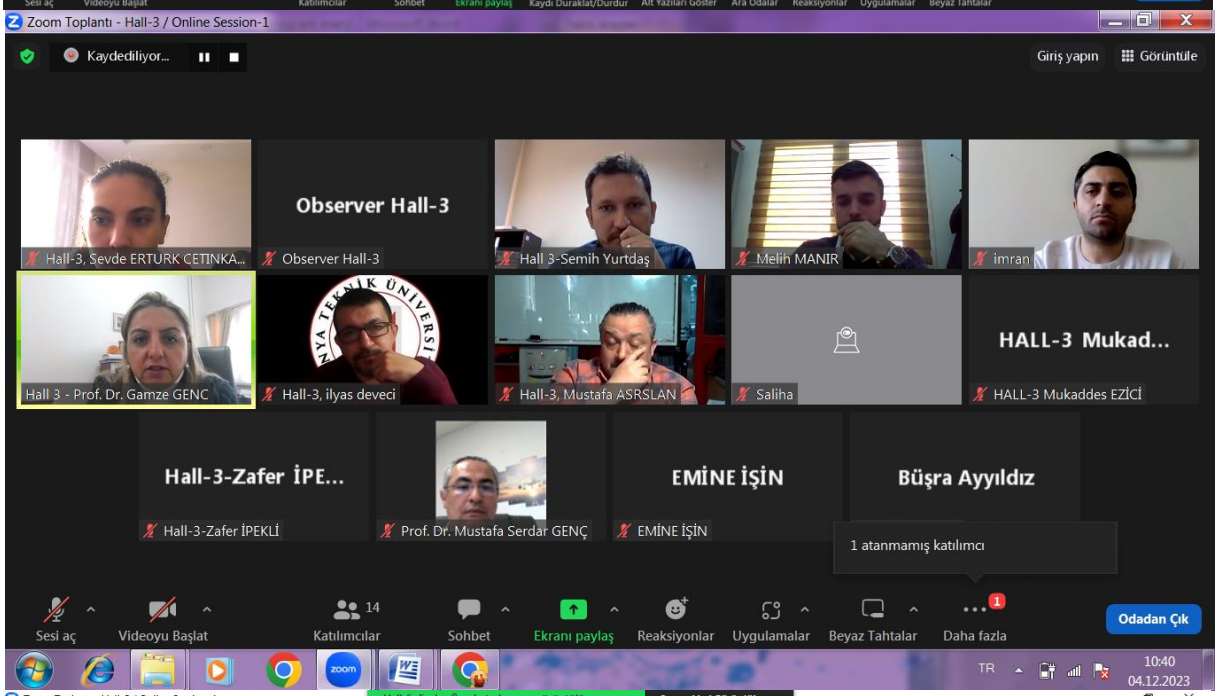
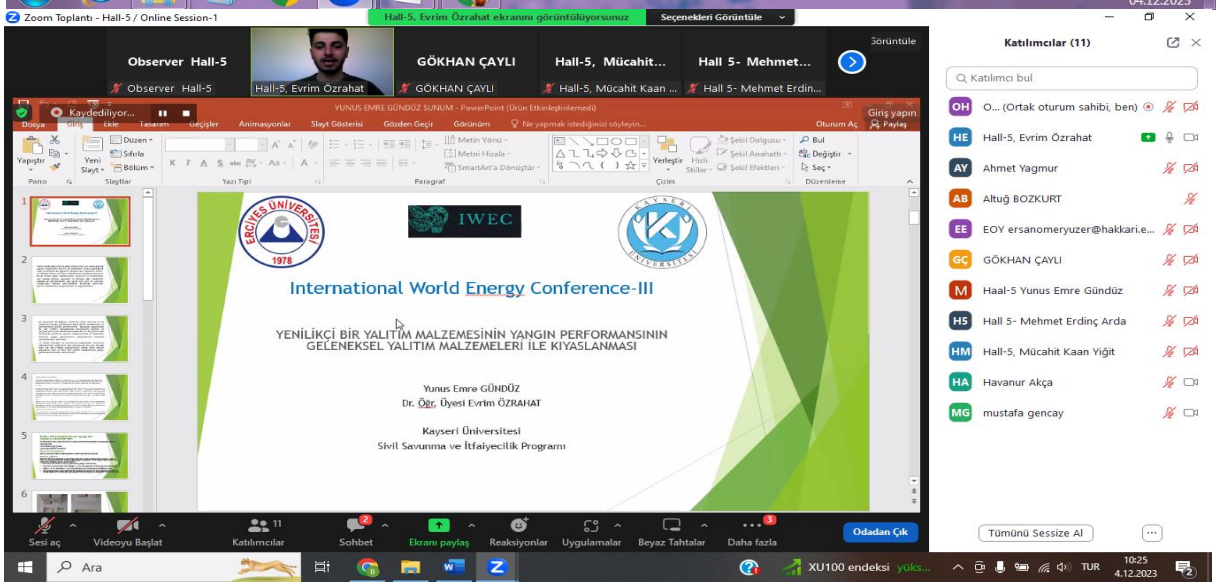
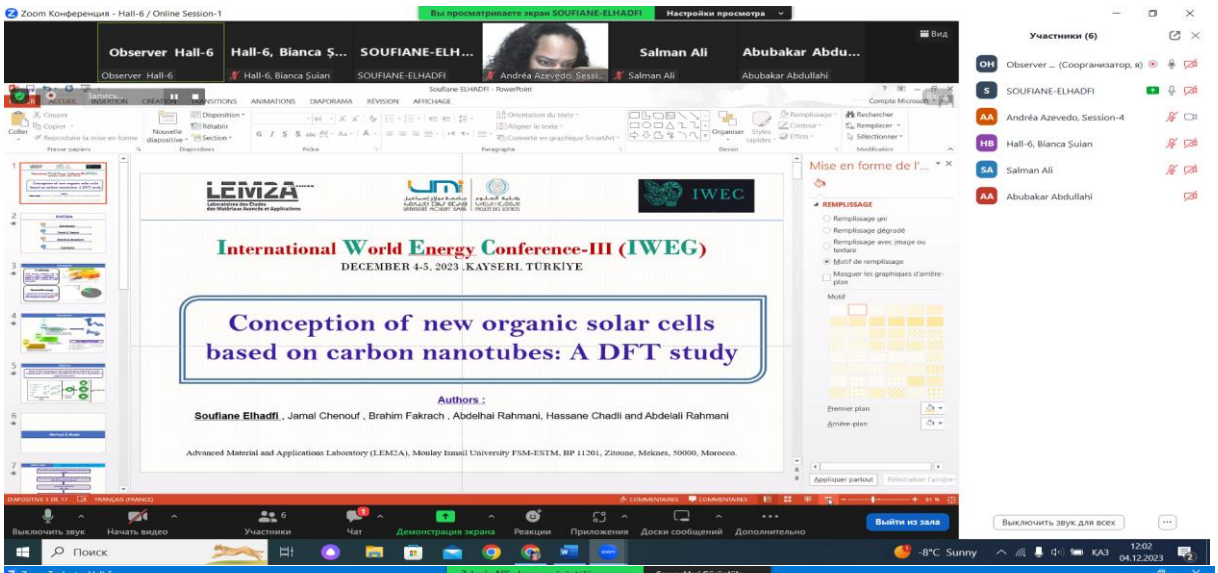

Giriş yapın
Görüntüle
Hall-1, Onur ATA
Observer H-1
Hall-1, Engin ŞİMŞEK
vasifcan.yildiran
Hall-1, Demet Yılmaz
Onur Karaaslan
Sercan Yagmur KTUN
Hall1-Session 1_Selma Akçay
Mehmet ORUÇ
Odadan Çık

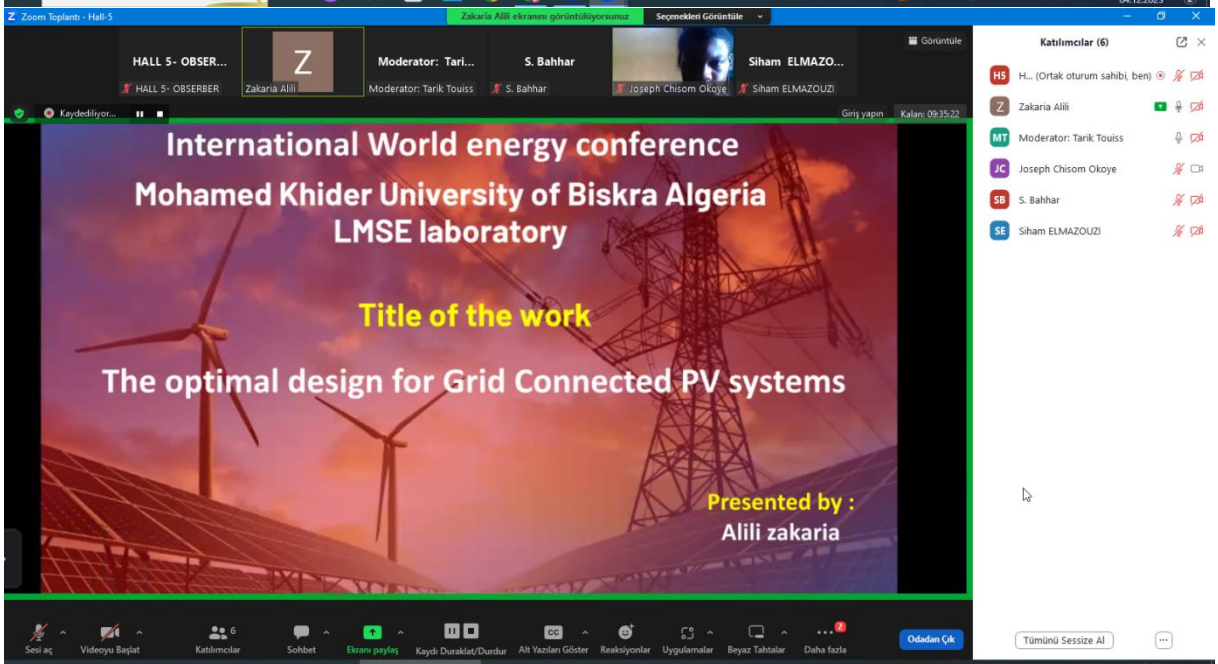

Kaydediliyor...
vasifcan.yildiran ekranını görüntülüyorsunuz
Seçenekleri Görüntüle
İTÜ
LITERATURE REVIEW
THE LITERATURE REVIEW OF THE EXPERIMENTAL STUDY CONDUCTED FOR A CONI
Effect of Heater Power
Inlet temp
Outlet temp
Drying air temperature at a HEX inlet
Drying air temperature at a HEX outlet
Drying time (min)
Variation of air temperature at the inlet and the outlet of the condensing heat exchanger (HEX) during the drying process
Difference of humidity ratio (g/kg)
Time (min)
Differences of humidity ratio between the inlet and the outlet of heat exchanger.
Effect of heater power on the t
and the drying time normalized
power of 2,300 W at the drying
m3/h, and the cooling air flow
Observer H-1
Hall-1, Engin ŞİMŞEK
vasifcan.yildiran
Hall-1, Demet Yı...
Hall-1, Demet Yılmaz
The total energy consumption rate has almost no relationship to the heater power. In addition, the larger the heater p
drying time. Total energy consumption is due to the fan and the heater power. This result means that the increase in the rate of energy use
by the heater is compensated by the decrease of the fan power due to the shorter drying time.
Sesi aç
Videoyu Başlat
Katılımcılar
Sohbet
Ekranı paylaş
Kaydı Duraklat/Durdur
Alt Yazıları Göster
Ara Odalar
Reaksiyonlar
Uygulamalar
Beyaz Tahtalar
Odadan Çık

Hall-2, Hakan SONMEZ-Dokuz Eylül University
OBSERVER H-2...
OBSERVER H-2 Ülkü EKSİN
muraterdem
ayşegül ozkan
Doç. Dr. İlkay NOYAN YALMAN
İBRAHİM SEZER BELLİLER
Hall-2, Kifayet E...
Hall-2, Kifayet ERDEM ARSLAN
Dr. İbrahim Öza...
Dr. İbrahim Özaytürk
Sinan Güneş
Sinan Güneş
Katılımcılar
Sohbet
Ekranı paylaş
Kaydı Duraklat/Durdur
Alt Yazıları Göster
Ara Odalar
Reaksiyonlar
Uygulamalar
Beyaz Tahtalar
Odadan Çık

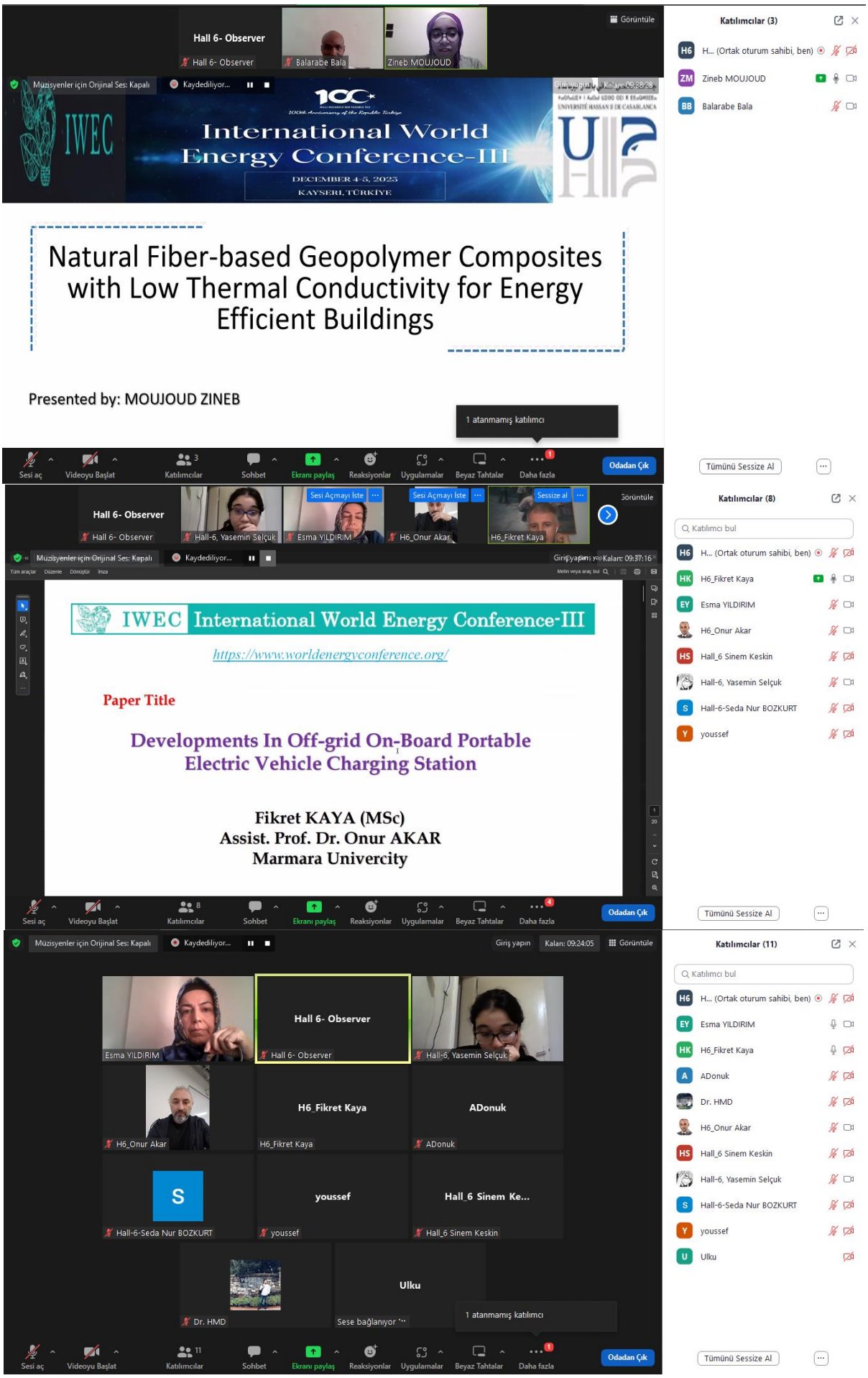

Zoom Toplantı - Hall-3 / Online Session-1
Kaydediliyor...
Giriş yapın
Görüntüle
Hall-3, Sevde ERTURK CETINKA...
Observer Hall-3
Observer Hall-3
Hall 3-Semih Yurtdaş
Melih MANIR
imran
Hall 3 - Prof. Dr. Gamze GENC
Hall-3, ilyas deveci
Hall-3, Mustafa ASRSLAN
Saliha
HALL-3 Mukad...
HALL-3 Mukaddes EZİCİ
Hall-3-Zafer İPE...
Hall-3-Zafer İPEKLİ
Prof. Dr. Mustafa Serdar GENÇ
EMİNE İŞİN
EMİNE İŞİN
Büşra Ayyıldız
1 atanmamış katılımcı
Sesi aç
Videoyu Başlat
Katılımcılar
Sohbet
Ekranı paylaş
Reaksiyonlar
Uygulamalar
Beyaz Tahtalar
Daha fazla
Odadan Çık
TR
10:40
04.12.2023

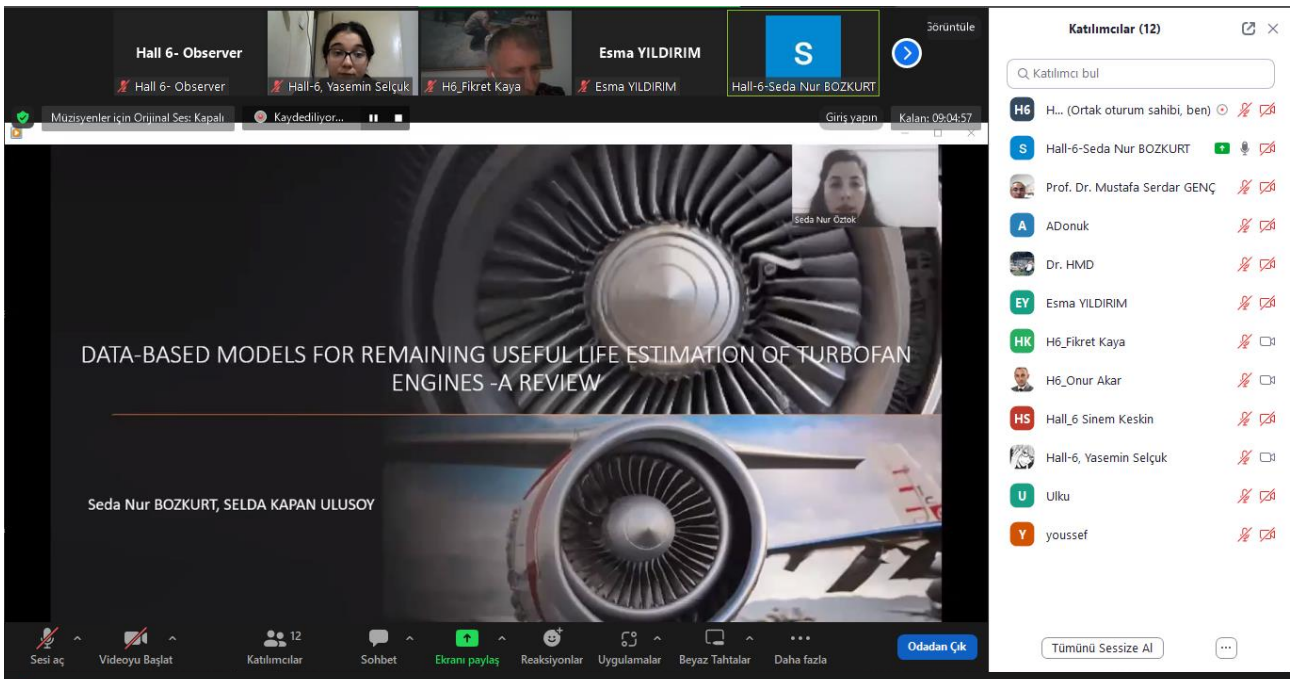

Zoom Toplantı - Hall-5 / Online Session-1
Hall-5, Evrim Özrahat ekranını görüntülüyorsunuz
Seçenekleri Görüntüle
Observer Hall-5
Hall-5, Evrim Özrahat
GÖKHAN ÇAYLI
Hall-5, Mücahit...
Hall 5- Mehmet...
Katılımcılar (11)
Katılımcı bul
O... (Ortak oturum sahibi, ben)
Hall-5, Evrim Özrahat
Ahmet Yagmur
Altuğ BOZKURT
EOY ersanomeryuzer@hakkari.e...
GÖKHAN ÇAYLI
Haal-5 Yunus Emre Gündüz
Hall 5- Mehmet Erdinç Arda
Hall-5, Mücahit Kaan Yiğit
Havanur Akça
mustafa gencay
IWEC
International World Energy Conference-III
YENİLİKÇİ BİR YALITIM MALZEMESİNİN YANGIN PERFORMANSININ GELENEKSEL YALITIM MALZEMELERİ İLE KIYASLANMASI
Yunus Emre GÜNDÜZ
Dr. Öğr. Üyesi Evrim ÖZRAHAT
Kayseri Üniversitesi
Sivil Savunma ve İtfaiyecilik Programı
Tümünü Sessize Al
Odadan Çık
10:25
4.12.2023

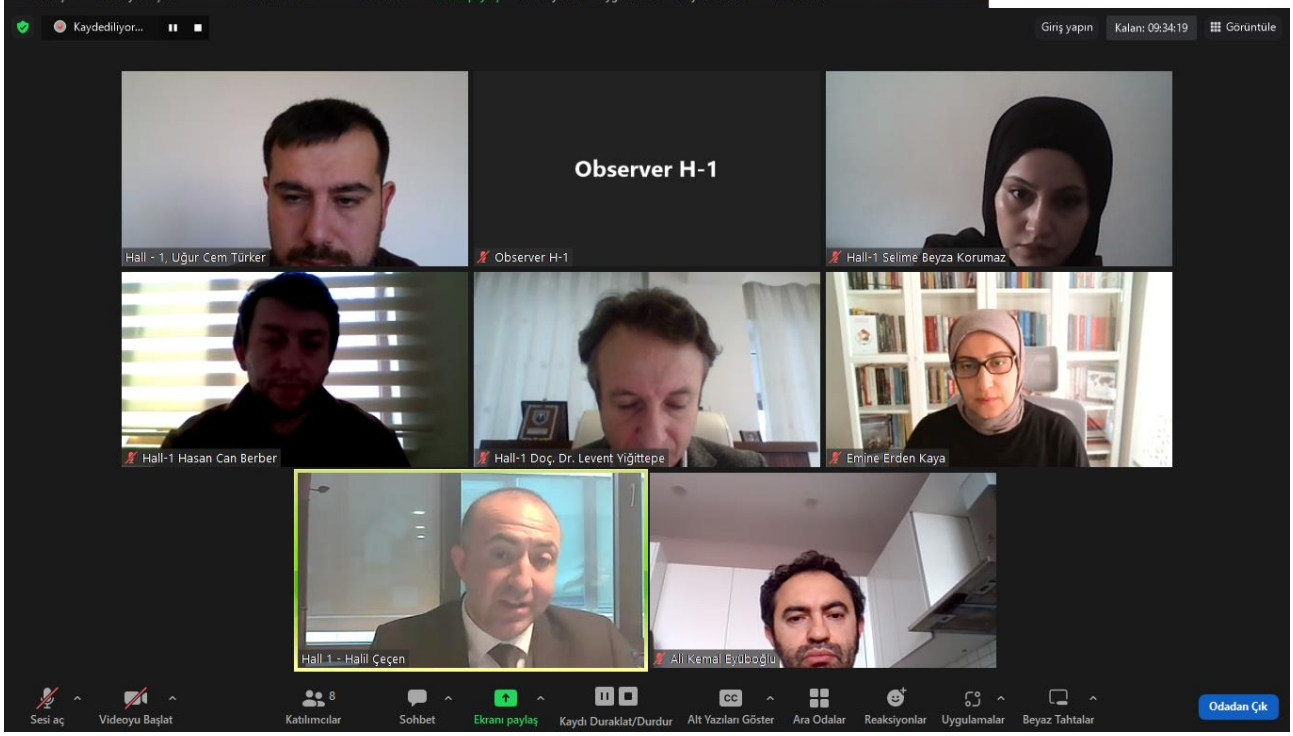

International World Energy Conference-III (IWEG)
DECEMBER 4-5, 2023 , KAYSERI, TÜRKİYE
Conception of new organic solar cells based on carbon nanotubes: A DFT study
Authors :
Soufiane Elhadfi , Jamal Chenouf , Brahim Fakrach , Abdelhai Rahmani, Hassane Chadli and Abdelali Rahmani
Advanced Material and Applications Laboratory (LEM2A), Moulay Ismail University FSM-ESTM, BP 11201, Zitoune, Meknes, 50000, Morocco.


International World energy conference
Mohamed Khider University of Biskra Algeria
LMSE laboratory
Title of the work
The optimal design for Grid Connected PV systems
Presented by :
Alili zakaria

esith
Constructeur de compétences
REMTEX
Laboratoire de REcherche sur les Matériaux TEXtiles
International World Energy
Conference-III
WORLD ENERGY CONFERENCE
FSBM
FACULTE DES SCIENCES BEN M'SICK
UNIVERSITÉ HASSAN II DE CASABLANCA
Numerical investigation of eco-friendly materials for building envelope
Dr. MRAJJI OUAHIBA
Email : ouahiba.mrajji@gmail.com
Laboratory textile materials research (REMTEX), Higher School of Textile and clothing Industries,Casablanca Morocco


Hall 6- Observer
Balarabe Bala
Zineb MOUJOUD
Katılımcılar (3)
IWEC
International World Energy Conference-III
DECEMBER 4-5, 2023
KAYSERI, TÜRKIYE
Natural Fiber-based Geopolymer Composites with Low Thermal Conductivity for Energy Efficient Buildings
Presented by: MOUJOUD ZINEB
1 atanmamış katılımcı
Katılımcılar (8)
IWEC International World Energy Conference-III
https://www.worldenergyconference.org/
Paper Title
Developments In Off-grid On-Board Portable Electric Vehicle Charging Station
Fikret KAYA (MSc)
Assist. Prof. Dr. Onur AKAR
Marmara Univercity
Katılımcılar (11)
Esma YILDIRIM
H6_Fikret Kaya
ADonuk
H6_Onur Akar
youssef
Hall_6 Sinem Ke...
Ulku
Dr. HMD
1 atanmamış katılımcı


Hall 6- Observer
Hall 6- Observer
Hall-6, Yasemin Selçuk
H6_Fikret Kaya
Esma YILDIRIM
Esma YILDIRIM
Hall-6-Seda Nur BOZKURT
Görüntüle
Müzisyenler için Orijinal Ses: Kapalı
Kaydediliyor...
Giriş yapın
Kalan: 09:04:57
Katılımcılar (12)
Katılımcı bul
H... (Ortak oturum sahibi, ben)
Hall-6-Seda Nur BOZKURT
Prof. Dr. Mustafa Serdar GENÇ
ADonuk
Dr. HMD
Esma YILDIRIM
H6_Fikret Kaya
H6_Onur Akar
Hall_6 Sinem Keskin
Hall-6, Yasemin Selçuk
Ulku
youssef
Seda Nur Öztok
DATA-BASED MODELS FOR REMAINING USEFUL LIFE ESTIMATION OF TURBOFAN ENGINES -A REVIEW
Seda Nur BOZKURT, SELDA KAPAN ULUSOY
Sesi aç
Videoyu Başlat
Katılımcılar
Sohbet
Ekranı paylaş
Reaksiyonlar
Uygulamalar
Beyaz Tahtalar
Daha fazla
Odadan Çık
Tümünü Sessize Al


Kaydediliyor...
Giriş yapın
Kalan: 09:34:19
Görüntüle
Hall - 1, Uğur Cem Türker
Observer H-1
Observer H-1
Hall-1 Selime Beyza Korumaz
Hall-1 Hasan Can Berber
Hall-1 Doç. Dr. Levent Yiğittepe
Emine Erden Kaya
Hall 1 - Halil Çeçen
Ali Kemal Byüboğlu
Sesi aç
Videoyu Başlat
Katılımcılar
Sohbet
Ekranı paylaş
Kaydı Duraklat/Durdur
Alt Yazıları Göster
Ara Odalar
Reaksiyonlar
Uygulamalar
Beyaz Tahtalar
Odadan Çık

Giriş yapın
Kalan: 09:55:54
Görüntüle
Hall 1- Kosovare Latifaj
Observer H-1
H1: Oluchukwu Faith JISIKE
Hall 1 - Prof. Ass. Dr. Bukurije Hoxha
H1, S4 Vijay Kumar
AMINA OUAHBI
hall-1 Oumaima CHAJII
Bekir Bytyqi
Hall-1, Alper Uğur
hall 5 Joseph Ch...
hall 5 Joseph Chisom Okoye
Sesi aç
Videoyu Başlat
Katılımcılar
Sohbet
Ekranı paylaş
Kaydet
Alt Yazıları Göster
Ara Odalar
Reaksiyonlar
Uygulamalar
Beyaz Tahtalar
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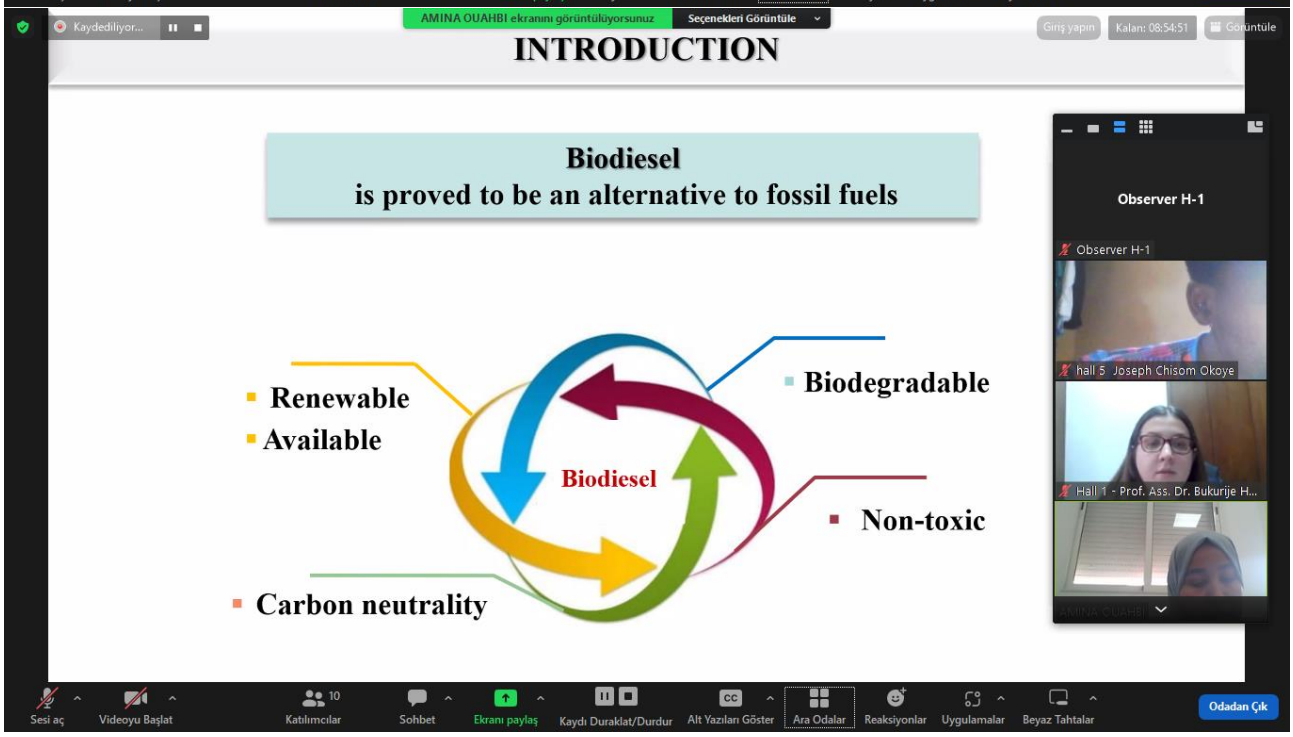
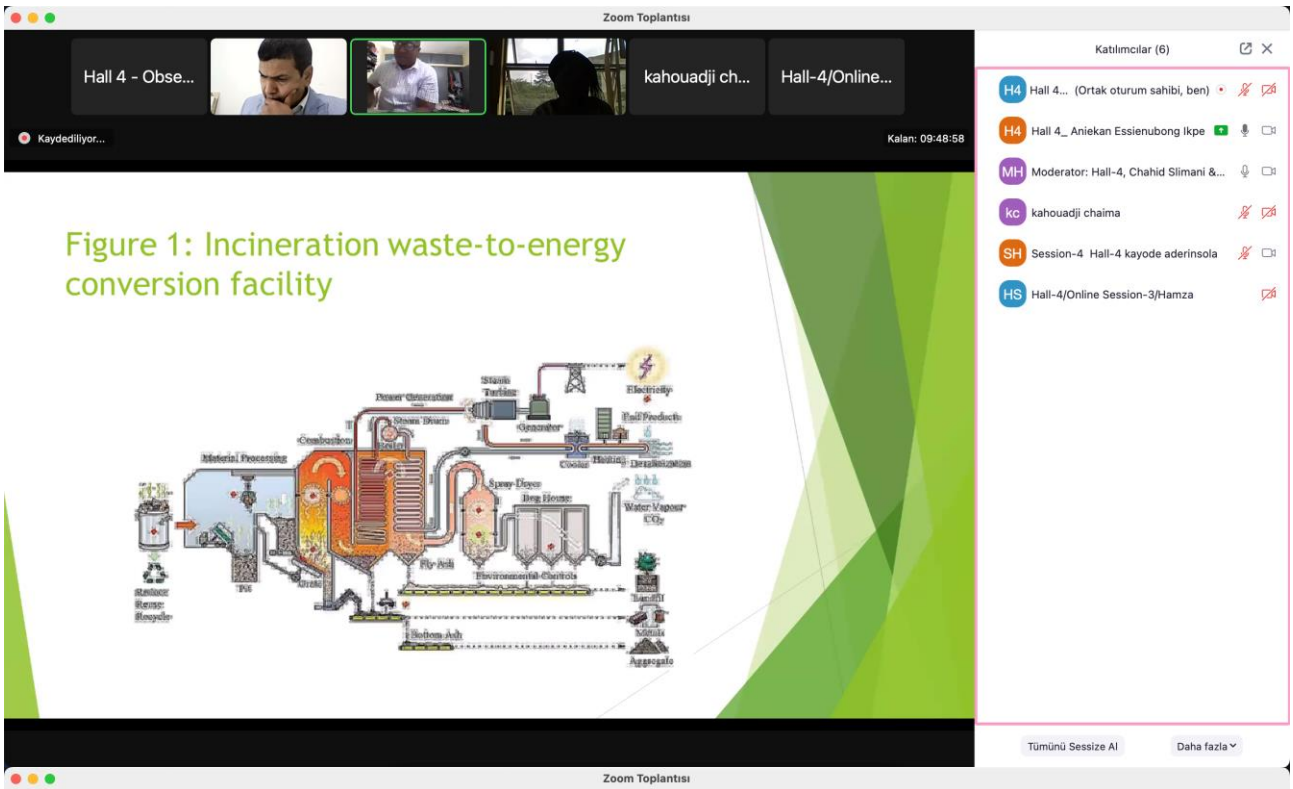
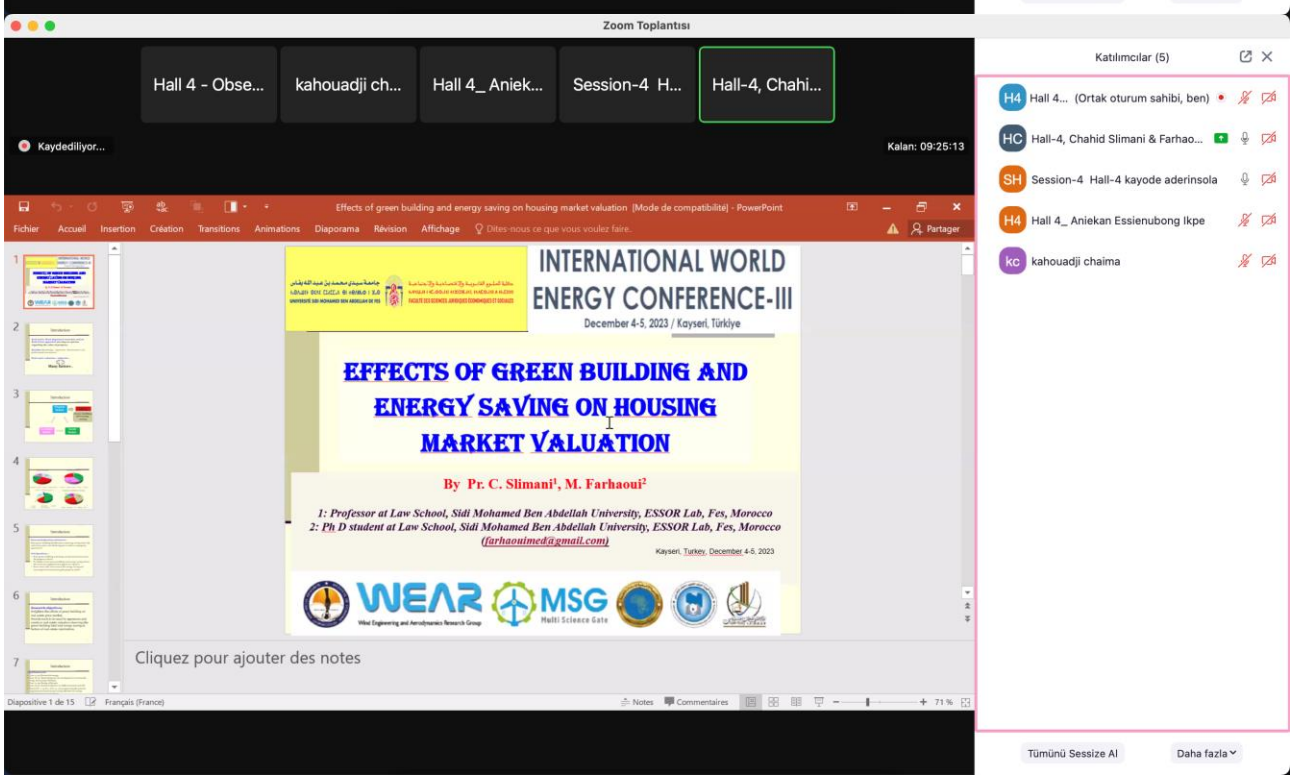
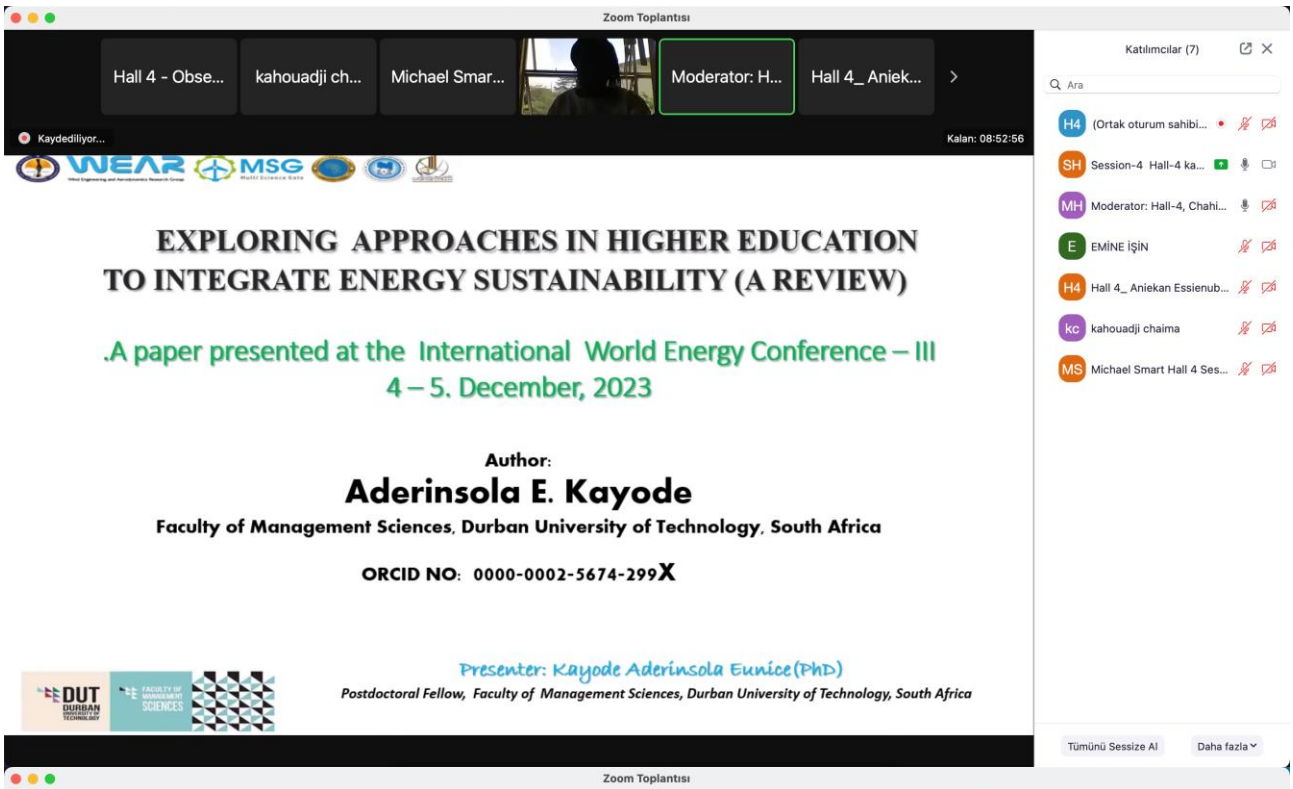

Kaydediliyor...
AMINA OUAHBI ekranını görüntülüyorsunuz
Seçenekleri Görüntüle
Giriş yapın
Kalan: 08:54:51
Görüntüle
INTRODUCTION
Biodiesel
is proved to be an alternative to fossil fuels
Renewable
Available
Biodegradable
Biodiesel
Non-toxic
Carbon neutrality
Observer H-1
hall 5 Joseph Chisom Okoye
Hall 1 - Prof. Ass. Dr. Bukurije H...
Sesi aç
Videoyu Başlat
Katılımcılar
Sohbet
Ekranı paylaş
Kaydı Duraklat/Durdur
Alt Yazıları Göster
Ara Odalar
Reaksiyonlar
Uygulamalar
Beyaz Tahtalar
Odadan Çık


Zoom Toplantısı
Hall 4 - Obse...
kahouadji ch...
Hall-4/Online...
Kaydediliyor...
Kalan: 09:48:58
Katılımcılar (6)
Hall 4... (Ortak oturum sahibi, ben)
Hall 4_ Aniekan Essienubong Ikpe
Moderator: Hall-4, Chahid Slimani &...
kahouadji chaima
Session-4 Hall-4 kayode aderinsola
Hall-4/Online Session-3/Hamza
Figure 1: Incineration waste-to-energy conversion facility
Tümünü Sessize Al
Daha fazla


Zoom Toplantısı
Hall 4 - Obse...
kahouadji ch...
Hall 4_ Aniek...
Session-4 H...
Hall-4, Chahi...
Kaydediliyor...
Kalan: 09:25:13
Katılımcılar (5)
Hall 4... (Ortak oturum sahibi, ben)
Hall-4, Chahid Slimani & Farhao...
Session-4 Hall-4 kayode aderinsola
Hall 4_ Aniekan Essienubong Ikpe
kahouadji chaima
INTERNATIONAL WORLD ENERGY CONFERENCE-III
December 4-5, 2023 / Kayseri, Türkiye
EFFECTS OF GREEN BUILDING AND ENERGY SAVING ON HOUSING MARKET VALUATION
By Pr. C. Slimani[1], M. Farhaoui[2]
1: Professor at Law School, Sidi Mohamed Ben Abdellah University, ESSOR Lab, Fes, Morocco
2: Ph D student at Law School, Sidi Mohamed Ben Abdellah University, ESSOR Lab, Fes, Morocco
(farhaouimed@gmail.com)
Kayseri, Turkey, December 4-5, 2023
Cliquez pour ajouter des notes
Tümünü Sessize Al
Daha fazla


Zoom Toplantısı
Hall 4 - Obse...
kahouadji ch...
Michael Smar...
Moderator: H...
Hall 4_ Aniek...
Kaydediliyor...
Kalan: 08:52:56
Katılımcılar (7)
Ara
(Ortak oturum sahibi...
Session-4 Hall-4 ka...
Moderator: Hall-4, Chahi...
EMİNE İŞİN
Hall 4_ Aniekan Essienub...
kahouadji chaima
Michael Smart Hall 4 Ses...
Tümünü Sessize Al
Daha fazla
EXPLORING APPROACHES IN HIGHER EDUCATION TO INTEGRATE ENERGY SUSTAINABILITY (A REVIEW)
.A paper presented at the International World Energy Conference – III
4 – 5. December, 2023
Author:
Aderinsola E. Kayode
Faculty of Management Sciences, Durban University of Technology, South Africa
ORCID NO: 0000-0002-5674-299X
Presenter: Kayode Aderinsola Eunice(PhD)
Postdoctoral Fellow, Faculty of Management Sciences, Durban University of Technology, South Africa

Zoom Toplantısı
Hall 4 - Obse...
Rukhsar khan
Kaydediliyor...
Kalan: 09:15:51
Katılımcılar (7)
Ara
Hall 4... (Ortak oturum sahibi, ben)
Hall-4 Moderator Sándor Földvári
Hall 4 : Prof. Deepak Bansal
Hall 4 : Prof. PADMA KANTA MISHRA -
hall-4, Andréa Azevedo
Rukhsar khan
Hall4 : Padma Kanta Mishra Presentation
Tümünü Sessize Al
Daha fazla
ENERGY SUPPLY FOR TÜRKIYE : OIL AND GAS IN UKRAINE UNDER THE BLACK SEA
TÜRKIYE IÇIN ENERJI KAYNAĞI: UKRAYNA PETROL VE GAZ KARADENİZ ALTINDA
INTERNATIONAL WO ENERGY CONFERENCE December 4-5, 2023 / Kayseri, Türkiye
UNIVERSITY of DEBRECEN
SÁNDOR FÖLDVÁRI
ORCID: 0000-0002-7825-0531
Research Scholar, Budapest, Hungary;
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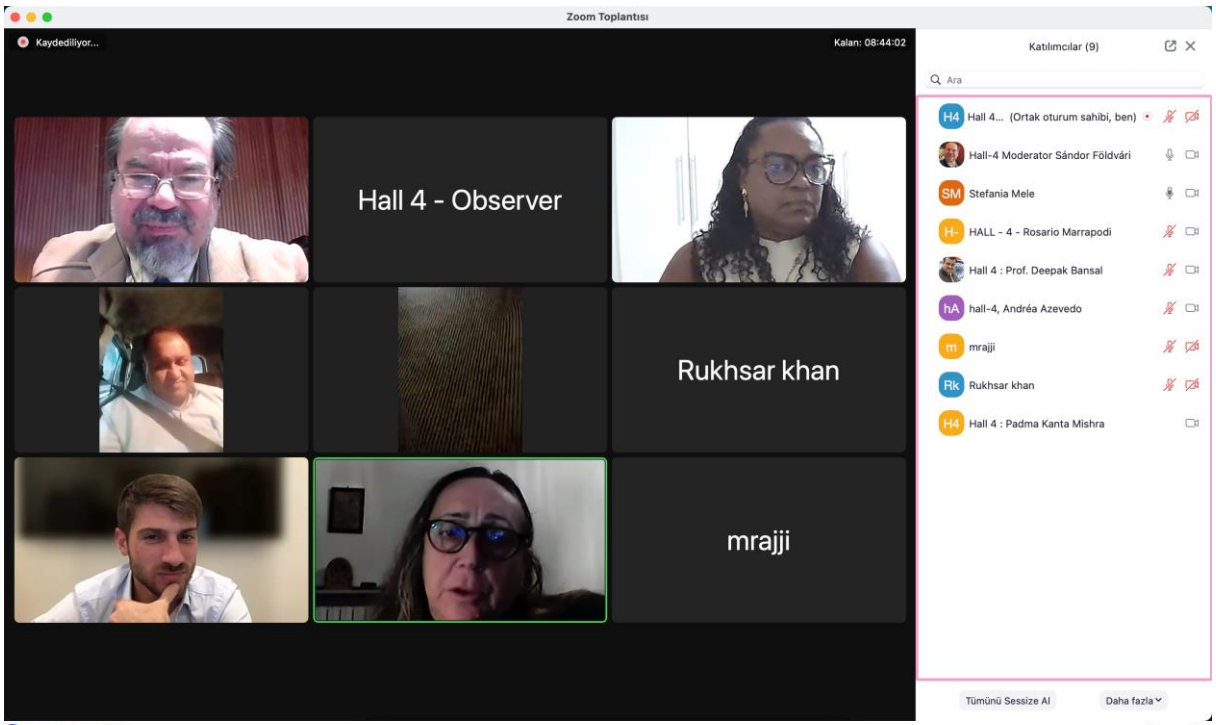
Kyiv, "Interdisciplinary Readings" Editorial Board member,
ASEEES; NIC; Asociatia Romana pentru Studii Baltice si Nordice


Zoom Toplantısı
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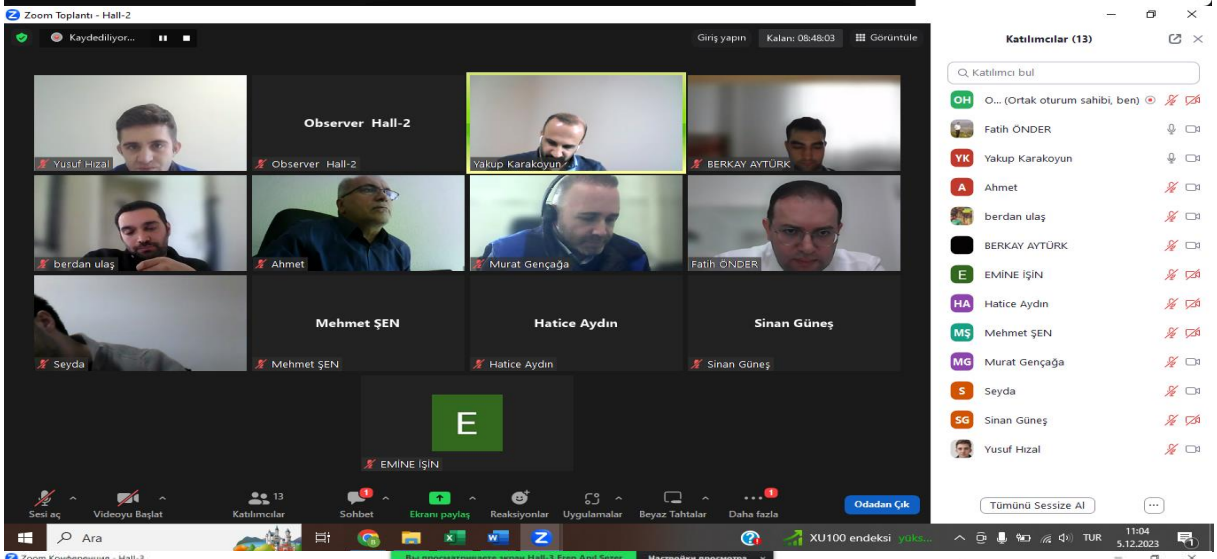
Kalan: 08:44:02
Hall 4 - Observer
Rukhsar khan
mrajji
Katılımcılar (9)
Ara
Hall 4... (Ortak oturum sahibi, ben)
Hall-4 Moderator Sándor Földvári
Stefania Mele
HALL - 4 - Rosario Marrapodi
Hall 4 : Prof. Deepak Bansal
hall-4, Andréa Azevedo
mrajji
Rukhsar khan
Hall 4 : Padma Kanta Mishra
Tümünü Sessize Al
Daha fazla


Zoom Toplantı - Hall-2
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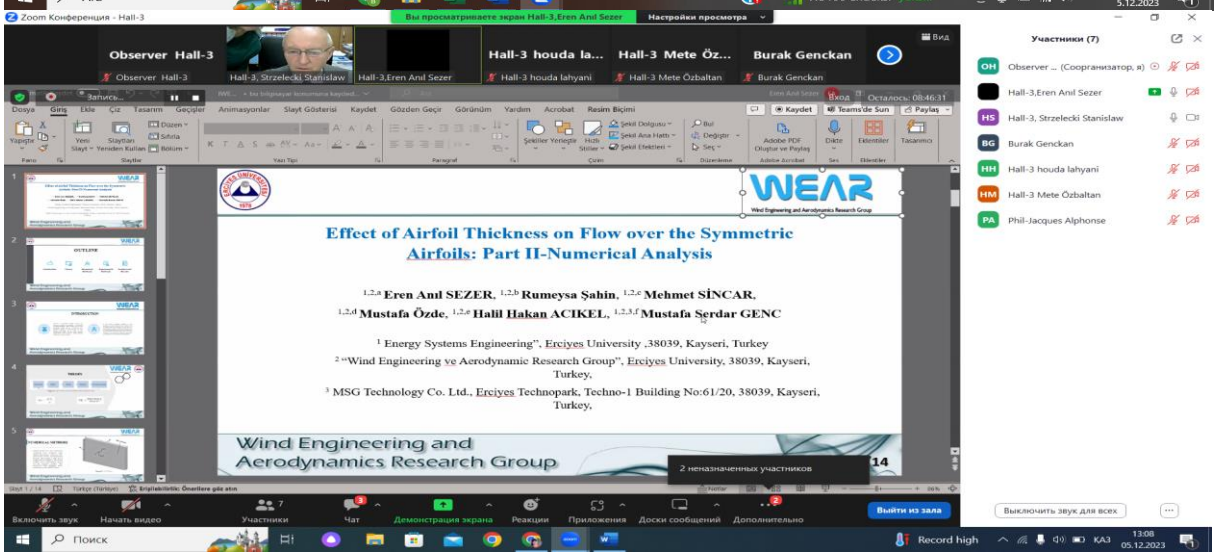
Kalan: 08:48:03
Görüntüle
Yusuf Hizal
Observer Hall-2
Yakup Karakoyun
BERKAY AYTÜRK
berdan ulaş
Ahmet
Murat Gençağa
Fatih ÖNDER
Seyda
Mehmet ŞEN
Hatice Aydın
Sinan Güneş
E
EMİNE İŞİN
Katılımcılar (13)
Katılımcı bul
O... (Ortak oturum sahibi, ben)
Fatih ÖNDER
Yakup Karakoyun
Ahmet
berdan ulaş
BERKAY AYTÜRK
EMİNE İŞİN
Hatice Aydın
Mehmet ŞEN
Murat Gençağa
Seyda
Sinan Güneş
Yusuf Hızal
Tümünü Sessize Al
Sesi aç
Videoyu Başlat
Katılımcılar
Sohbet
Ekranı paylaş
Reaksiyonlar
Uygulamalar
Beyaz Tahtalar
Daha fazla
Odadan Çık


Zoom Конференция - Hall-3
Observer Hall-3
Hall-3, Strzelecki Stanislaw
Hall-3,Eren Anıl Sezer
Hall-3 houda la...
Hall-3 Mete Öz...
Burak Genckan
Effect of Airfoil Thickness on Flow over the Symmetric Airfoils: Part II-Numerical Analysis
Eren Anıl SEZER, Rumeysa Şahin, Mehmet SİNCAR,
Mustafa Özde, Halil Hakan ACIKEL, Mustafa Serdar GENC
Energy Systems Engineering", Erciyes University ,38039, Kayseri, Turkey
"Wind Engineering ve Aerodynamic Research Group", Erciyes University, 38039, Kayseri, Turkey,
MSG Technology Co. Ltd., Erciyes Technopark, Techno-1 Building No:61/20, 38039, Kayseri, Turkey,
Wind Engineering and Aerodynamics Research Group
Участники (7)
Observer ... (Соорганизатор, я)
Hall-3,Eren Anıl Sezer
Hall-3, Strzelecki Stanislaw
Burak Genckan
Hall-3 houda lahyani
Hall-3 Mete Özbaltan
Phil-Jacques Alphonse
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Участники
Чат
Демонстрация экрана
Реакции
Приложения
Доски сообщений
Дополнительно
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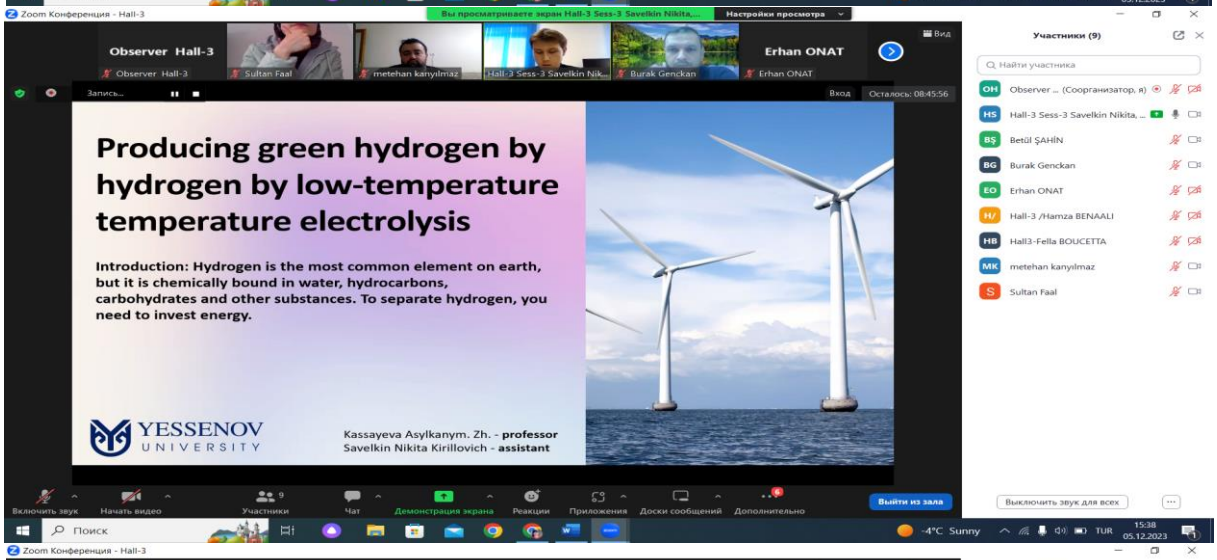
Zoom Конференция - Hall-3
Observer Hall-3
Hall-3, Saliha Özarslan
Sultan Faal
metehan kanyilmaz
Erhan ONAT
Burak Genckan
3. International World Energy Congress
4-5 December 2023, Kayseri
Modelling Combustion of Biomass Tea Waste in a Vertical Furnace Under Different Excess Air Ratios: A CFD Analysis
Saliha ÖZARSLAN[1], Melih YILDIZ[2]*
[1]Amasya University, Technical Sciences Vocational School, Automotive Program, Amasya, Türkiye
[2] Iğdır University, Faculty of Engineering, Department of Mechanical Engineering, Iğdır, Türkiye
Участники (8)
Observer ... (Соорганизатор, я)
Hall-3, Saliha Özarslan
Sultan Faal
Burak Genckan
Erhan ONAT
Hall-3 Sess-3 Savelkin Nikita, Ass...
metehan kanyilmaz
Ayetül Gelen (Hall-3)


Zoom Конференция - Hall-3
Observer Hall-3
Sultan Faal
metehan kanyilmaz
Hall-3 Sess-3 Savelkin Nik...
Burak Genckan
Erhan ONAT
Producing green hydrogen by hydrogen by low-temperature temperature electrolysis
Introduction: Hydrogen is the most common element on earth, but it is chemically bound in water, hydrocarbons, carbohydrates and other substances. To separate hydrogen, you need to invest energy.
YESSENOV UNIVERSITY
Kassayeva Asylkanym. Zh. - professor
Savelkin Nikita Kirillovich - assistant
Участники (9)
Observer ... (Соорганизатор, я)
Hall-3 Sess-3 Savelkin Nikita, ...
Betül ŞAHİN
Burak Genckan
Erhan ONAT
Hall-3 /Hamza BENAALI
Hall3-Fella BOUCETTA
metehan kanyilmaz
Sultan Faal

Zoom Конференция - Hall-3
Observer Hall-3
Hall-3 Ben Obakpo Johnson
AYKUT FATİH GÜVEN
HALL 3-EMİNE İŞİN
Hall3-Fella BOUCETTA
Hall3-Emn
Hall3-Gökhan K...
Hall3-Gökhan KEVEN
3 неназначенных участников
Участники (7)
Observer Hall... (Соорганизатор, я)
AYKUT FATİH GÜVEN
HALL 3-EMİNE İŞİN
Hall-3 Ben Obakpo Johnson
Hall3-Emn
Hall3-Fella BOUCETTA
Hall3-Gökhan KEVEN

Zoom Конференция - Hall-3
Вы просматриваете экран Gökhan KEVEN
Observer Hall-3
AYKUT FATİH GÜVEN
HALL 3-EMİNE İŞİN
Hall3-Fella BOUCETTA
Gökhan KEVEN
Mustafa Kaplan
Участники (7)
INTERNATIONAL WORLD ENERGY CONFERENCE-III
December 4-5, 2023 / Kayseri, Türkiye
REDUCED HARMONICS IN A SEVEN LEVEL ASYMMETRIC MULTILEVEL INVERTER WITH APERIODIC DC SOURCES
DR. GÖKHAN KEVEN
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Чат
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Реакции
Приложения
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Дополнительно
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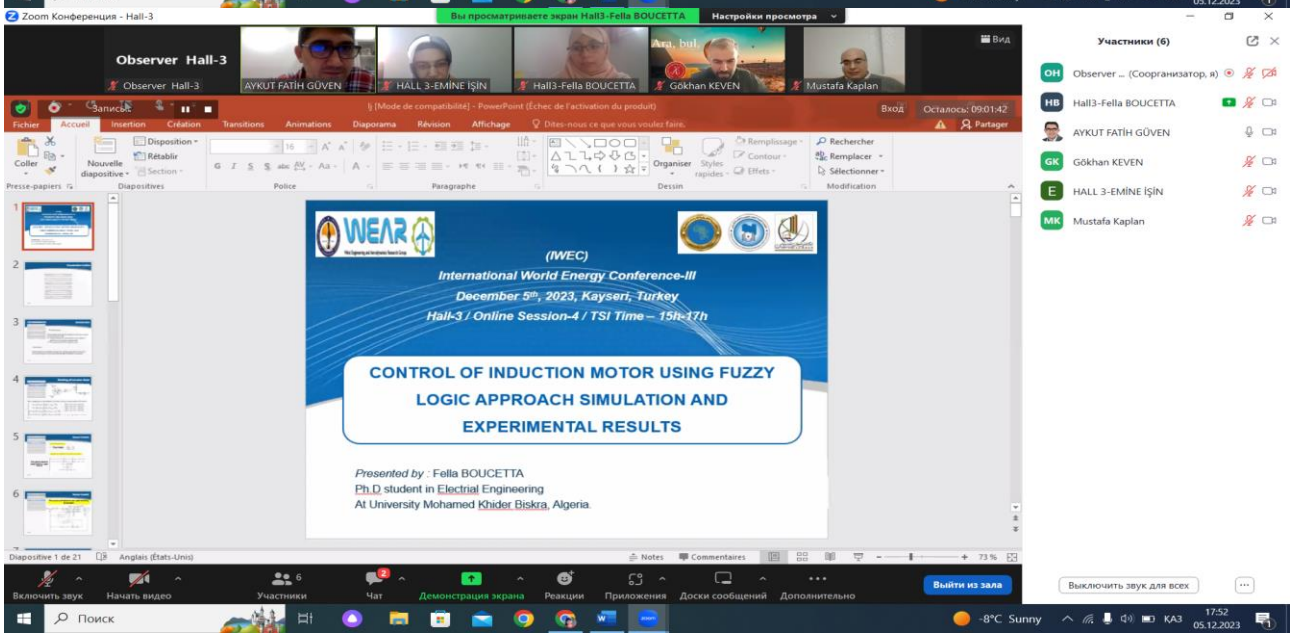
Zoom Конференция - Hall-3
Вы просматриваете экран Hall3-Fella BOUCETTA
Observer Hall-3
AYKUT FATİH GÜVEN
HALL 3-EMİNE İŞİN
Hall3-Fella BOUCETTA
Gökhan KEVEN
Mustafa Kaplan
Участники (6)
(IWEC)
International World Energy Conference-III
December 5th, 2023, Kayseri, Turkey
Hall-3 / Online Session-4 / TSI Time – 15h-17h
CONTROL OF INDUCTION MOTOR USING FUZZY LOGIC APPROACH SIMULATION AND EXPERIMENTAL RESULTS
Presented by : Fella BOUCETTA
Ph.D student in Electrial Engineering
At University Mohamed Khider Biskra, Algeria
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Участники
Чат
Демонстрация экрана
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Приложения
Доски сообщений
Дополнительно
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INTERNATIONAL WORLD ENERGY CONFERENCE-III

December 4-5, 2023 / Kayseri, Türkiye

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exp. Atabek Movlyanov

Wind Engineering and Aerodynamics Research Group

Multi Science Gate

-OPENING CEREMONY-

DATE: 04.12.2023 / TSI TIME-09^{00}:10^{00}

Zoom ID: 833 1287 1999 / Passcode: 100100

Prof. Dr. Mustafa Serdar GENÇ

Erciyes University, Director of the Energy Conversions Research and Application Center

HEAD OF CONFERENCE

Prof. Dr. İ. Engin TÜRE

Chairman of the Board at Clean Energy Foundation

INVITED SPEAKER

"Solar Cooling"

Ord. Prof. Dr. Beycan İBRAHİMOĞLU

Ankara Science University

INVITED SPEAKER

"Maddelerin Faz Diyagramı"

04.12.2023 / In-person Session-1 / TSI Time-13^{30}:15^{30}

VENUE: Erciyes University, Faculty of Engineering, Conference Hall (-1 floor, Next to the Canteen)

HEAD OF SESSION: Prof. Dr. Gamze GENÇ

Authors	Affiliation	Presentation title
Res. Assist. Selen AVCI AZKESKİN **Res. Assist. Ezgi GÜLER** **Zerrin ALADAĞ**	Kocaeli University, Türkiye Bilecik Şeyh Edebali University, Türkiye	ANALYSIS OF TÜRKİYE'S PROVINCES BASED ON ENERGY NEEDS USING MACHINE LEARNING METHODS
Res. Assist. Selen AVCI AZKESKİN **Res. Assist. Ezgi GÜLER** **Zerrin ALADAĞ**	Kocaeli University, Türkiye Bilecik Şeyh Edebali University, Türkiye	FUZZY CLUSTERING OF TÜRKİYE'S PROVINCES ACCORDING TO RENEWABLE ENERGY POTENTIALS
Kübra Turgut **Sinem Altinisik** **Gizem Yanalak** **Sermet Koyuncu** **İmren Hatay Patır**	Selcuk University, Türkiye Canakkale Onsekiz Mart University, Türkiye	EVALUATION OF PHOTOCATALYTIC HYDROGEN PRODUCTION ACTIVITY AND PHOTOELECTROCHEMICAL MEASUREMENTS OF TPCBP-B_TiO_2 PHOTOCATALYST
Kübra Turgut **Gizem Yanalak** **Adem Sarılmaz** **Faruk Özel** **İmren Hatay Patır**	Selcuk University, Türkiye Karamanoglu Mehmetbey University, Türkiye	EXAMINATION OF CESIUM BROMIDE PHOTOCATALYST FOR PHOTOCATALYTIC HYDROGEN PRODUCTION
Özgenur DİNÇER ŞAHAN **Ahmet KARADAĞ** **Attia HAMİD**	Yozgat Bozok University, Türkiye	ONE OF THE SECOND GENERATION ENERGY SOURCES FOR AGRICULTURAL ENERGY: INDUSTRIAL HEMP
Esra ÇELİK **Assist. Prof. Dr. Saltuk Buğra SELÇUKLU**	Republic of Türkiye Ministry of Energy and Natural Resources, Türkiye Erciyes University, Türkiye	ANALYSIS OF TÜRKIYE'S NUCLEAR ENERGY POLICIES WITHIN THE SCOPE OF COMBATING CLIMATE CHANGE AND EMISSION TARGETS
Salman Ali **Romolo Di Bernardo** **Fabrizio Marignetti** **Giovanni Busatto**	University of Cassino and Southern Lazio, Italy	ENHANCING PERFORMANCE OF PRINTED CIRCUIT BOARD AXIAL FLUX PERMANENT MAGNET MACHINES (PCB-AFPMM) THROUGH HEAT SINK INTEGRATION

04.12.2023 / In-person Session-2 / TSI Time-15^{30}:17^{30}

VENUE: Erciyes University, Faculty of Engineering, Conference Hall (-1 floor, Next to the Canteen)

HEAD OF SESSION: Prof. Dr. Mustafa Serdar GENÇ

Authors	Affiliation	Presentation title
Ayberk Salim MAYIL **Burcu KARA ER** **Can UĞURELLİ** **Nurhan VATANSEVER**	Haier Europe Research and Development Center, Türkiye	ENERGY EFFICIENCY CALCULATIONS ON RADIANT HOBS AND INDUCTION HOBS
Bahadır ÖZELER **Assoc. Prof. Dr. Merve KALEM**	Konya Teknik University, Türkiye	EVALUATION OF THE SOLID PRODUCT OBTAINED FROM PLASTIC WASTE PYROIYSIS IN ALTERNATIVE FUEL PRODUCTION
Ayberk Salim MAYIL **Vasıf Can YILDIRAN**	Haier Europe Research and Development Center, Türkiye	EVALUATION OF DOMESTIC BUILT-IN OVEN COOLING SYSTEMS USING CFD ANALYSIS
Büşra AYYILDIZ **Dr. Kanber SEDEF** **Prof. Dr. Mustafa Serdar GENÇ**	Erciyes University, Türkiye Dener Machinery Inc., Türkiye	NEW REGENERATIVE BRAKING APPROACH; ROAD TOPOLOGY MODELING
Yernat Zhuamdil **Halil ÖZTÜRK** **Berkay KABAL** **Ünal UYSAL** **Ali ÇORUH**	Sakarya University, Türkiye	HYBRID VERTICAL WIND TURBINE DESIGN
Prof. Dr. Volkan KALEM **Assoc. Prof. Dr. İlyas ŞAVKLIYILDIZ**	Konya Technical University, Türkiye	DIELECTRIC AND PIEZOELECTRIC PROPERTIES OF BNT-BKT CERAMICS PREPARED BY SOLUTION COATING METHOD
Assist. Prof. Dr. Emrah ÇETİN **Zeynep TÜFEK**	Bozok University, Türkiye	COMPARISON OF STORAGE TECHNOLOGIES IN POWER SYSTEMS INCLUDING RENEWABLE ENERGY PLANTS

04.12.2023 / Hall-1 / Online Session-1 / TSI Time - 10^{00}:12^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Prof. Dr. Demet YILMAZ

Authors	Affiliation	Presentation title
Assist. Prof. Dr. Selma AKÇAY	Çankırı Karatekin University, Türkiye	HEAT TRANSFER ANALYSIS IN A STRAIGHT CHANNEL CONTAINING AN EXPANDING CHAMBER WITH WINGLETS
Prof. Dr. Sennur ALAY AKSOY **Prof. Dr. Demet YILMAZ**	Süleyman Demirel University, Türkiye	PRODUCTION OF POLYESTER RING SPUN YARNS WITH THERMOREGULATING FUNCTION CONTAINING MICROENCAPSULATED PHASE CHANGE MATERIALS (PCM) FOR PERSONAL THERMAL MANAGEMENT (PTM) APPLICATIONS
Engin ŞİMŞEK **Korhan ÖKTEN**	Amasya University, Türkiye	COMPARISON OF HYBRID AND ACTIVE PV COOLING SYSTEMS WITH A 1-D MATHEMATICAL MODEL BASED ON CONCENTRATION RATIO
Vasıf Can YILDIRAN **Prof. Dr. Hasan GÜNEŞ**	Istanbul Technical University, Türkiye	EXPERIMENTAL INVESTIGATION OF DRYING AND ENERGY PERFORMANCE IN A CONDENSER TUMBLE DRYER
Onur ATA **Prof. Dr. Özlem ONAY** **Assist. Prof. Dr. Emre TÜFEKÇİOĞLU**	Eskişehir Technical University, Türkiye	MODELING THE ENERGY OBTAINED BY PIEZOELECTRIC ENERGY HARVESTING FROM THE VIBRATION OF AN ELECTRIC MOTOR
Assist. Prof. Dr. Sercan DOGAN **Assist. Prof. Dr. Sercan YAGMUR** **Assoc. Prof. Dr. Aziz Hakan ALTUN**	Konya Technical University, Türkiye Selcuk University, Türkiye	FIRE SIMULATION FOR CLOSED CAR PARK IN THE SHOPPING CENTER
Onur KARAASLAN **Prof. Dr. Hasan GÜNEŞ**	Istanbul Technical University, Türkiye	HEAT SHIELD DESIGN AND ANALYSIS FOR THE COMBUSTION CHAMBER SYSTEM IN TURBOJET ENGINES
Res. Assist. Mehmet ORUÇ **Prof. Dr. Sedat YAYLA**	Van Yuzuncu Yil University, Türkiye	EXPERIMENTAL INVESTIGATION OF OIL-WATER SEPARATION EFFICIENCY

04.12.2023 / Hall-2 / Online Session-1 / TSI Time - 10^{00}:12^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Dr. Hakan SÖNMEZ

Authors	Affiliation	Presentation title
Dr. İbrahim ÖZAYTÜRK	Nigde Omer Halisdemir University, Türkiye	THE IMPACT OF SHALE GAS USAGE OF US TO TURKISH FOREIGN TRADE DEFICIT
Assoc. Prof. Dr. İlkay Noyan YALMAN **Lect. Dr. Kifayet ERDEM ARSLAN**	Cumhuriyet University, Türkiye	RENEWABLE ENERGY POTENTIAL AND INVESTMENTS IN THE TR72 REGION
Lect. Dr. Murat ERDEM **Assist. Prof. Dr. Mert GÜRTÜRK**	Fırat University, Türkiye	AN ANALYSIS ON TURKEY'S PREVIOUS RENEWABLE ENERGY SUPPORT MECHANISM
Dr. Hakan SÖNMEZ	Dokuz Eylul University, Türkiye	EFFECT OF ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSIONS ON ECONOMIC GROWTH IN TURKEY: EMPIRICAL EVIDENCE FROM THE AGRICULTURAL SECTOR
Dr. Ahmet DEMİRALP **Res. Assist. İbrahim Sezer BELLİLER**	Harran University, Türkiye	THE RELATIONSHIP BETWEEN CARBON DIOXIDE EMISSIONS AND OIL CONSUMPTION IN SELECTED EUROPEAN COUNTRIES: EVIDENCE FROM NONLINEAR ARDL MODELS
Res. Assist. İbrahim Sezer BELLİLER **Dr. Ahmet DEMİRALP**	Harran University, Türkiye	ARE CARBON DIOXIDE EMISSIONS CONVERGING IN SELECTED EUROPEAN COUNTRIES? EVIDENCE FROM NON-LINEAR UNIT ROOT TESTS
Res. Assist. Ayşegül ÖZKAN	Uşak University, Türkiye	THE RELATIONSHIP BETWEEN RENEWABLE ENERGY CONSUMPTION AND EMPLOYMENT: THE CASE OF TURKEY

04.12.2023 / Hall-3 / Online Session-1 / TSI Time - 10^{00}:12^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Prof. Dr. Gamze GENÇ

Authors	Affiliation	Presentation title
Mukaddes EZİCİ **Yunus Emre ÖZDEMİR** **Metin YAVUZ**	Ondokuz Mayıs University, Türkiye Republic Of Türkiye Ministry Of Agriculture And Forestry Black Sea Agricultural Research Institute, Türkiye	A COMPREHENSIVE ANALYSIS OF SOLAR CELL PATENTS
Res. Assist. Dr. Semih YURTDAŞ	Karamanoğlu Mehmetbey University, Türkiye	EFFECT OF Na DOPED ZnO BUFFER LAYER ON EFFICIENCY IN ORGANIC SOLAR CELLS
Melih MANIR **Prof. Dr. Gamze GENÇ** **Prof. Dr. Murat TOMAKİN** **Prof. Dr. Vagif NEVRUZOĞLU**	Recep Tayyip Erdogan University, Türkiye Erciyes University, Türkiye	INVESTIGATION OF PHOTOVOLTAIC PROPERTIES OF n-CdS/p-Cu2S SOLAR CELLS PRODUCED BY THREE DIFFERENT METHODS
Imran KANMAZ **Prof. Dr. Murat TOMAKİN** **Göksel AYTEMİZ** **Melih MANIR** **Prof. Dr. Vagif NEVRUZOĞLU**	Recep Tayyip Erdogan University, Türkiye	THE EFFECT OF THERMAL TREATMENT CONDITIONS ON THE BAND-GAP PROPERTIES OF TiO_2 THIN FILMS DEPOSITED ON QUARTZ GLASS
Lect. Dr. Mustafa ARSLAN **Lect. Cemile ARSLAN** **Lect. Gökhan YALÇIN**	Konya Technical University, Türkiye	EXPERIMENTAL SETUP FOR INVESTIGATING THE PERFORMANCE OF PHOTOVOLTAIC PANELS UNDER DIFFERENT CLIMATE CONDITIONS
Lect. Dr. Mustafa ARSLAN **Assist. Prof. Dr. İlyas DEVECİ** **Res. Assist. Emre ÜNVER**	Konya Technical University, Türkiye	THE EFFECT OF SOIL SAMPLES COLLECTED FROM SOLAR POWER PLANTS IN KONYA PROVINCE ON PHOTOVOLTAIC PANEL EFFICIENCY
Sevde ERTÜRK ÇETİNKAYA **Prof. Dr. Gamze GENÇ** **Assist. Prof. Dr. Muhammet ÇELİK**	Erciyes University, Türkiye	NUMERICAL ANALYSIS OF THE BEHAVIOR OF DIFFERENT ANODE MATERIALS IN LITHIUM-ION BATTERIES

04.12.2023 / Hall-4 / Online Session-1 / TSI Time - 10^{00}:12^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Prof. Dr. Dilek ERDİRENÇELEBİ

Authors	Affiliation	Presentation title
Prof. Dr. Dilek ERDİRENÇELEBİ	Konya Technical University, Türkiye	BENEFITS OF TEMPERATURE AND MIXING MODE VARIATIONS IN THE MONO- AND CO-DIGESTION ON THE SLUDGE LINE OF MUNICIPAL WWTPS
Lect. Dr. Fatma ŞENER FİDAN	Abdullah Gül University, Türkiye	A COMPARATIVE ANALYSIS OF WASTE DISPOSAL METHODS AND METHODOLOGIES ABOUT GREENHOUSE GAS EMISSIONS FOR ACHIEVING A SUSTAINABLE FUTURE
Prof. Dr. Dilek ERDİRENÇELEBİ	Konya Technical University, Türkiye	ANAEROBIC DIGESTION CHARACTERISTICS OF PRIMARY AND SECONDARY SEWAGE SLUDGES AT LOW ORGANIC LOADING RATES AT THE UPPER MESOPHILIC LEVEL
Assoc. Prof. Dr. Skender Demaku **Donika Sylejmani** **Arbnorë Aliu** **Ermond Frangu** **Lumturie Shkodra** **Leonita Dugolli**	University of Pristina, Kosovo	CHEMICAL, PHYSICAL AND BIOLOGICAL ANALYSIS OF RIVER WATER AND SEDIMENT; SITNICA, IBRI, TREPÇA AND DRENICA - CORRELATION WITH EU STANDARDS – FOR SURFACE WATERS
Assoc. Prof. Dr. Skender Demaku **Donika Sylejmani** **Arbnorë Aliu** **Bahrije Dobra** **Islam Zuzaku** **Muhamet Kiqina** **Alma Ejupi** **Aurita Muji**	University of Pristina, Kosovo	HEAVY METALS AS WATER AND SEDIMENT POLLUTANTS OF THE LLAP RIVER, DISTRICT; PODUJEV-LLUZHAN-BARILEV
Usman Aliyu Taliyawa **Yahaya Ado Gashua**	Federal University Dutsin-Ma, Nigeria	ECONOMIC VIABILITY OF CARBON CAPTURE AND STORAGE (CCS) TECHNOLOGIES: ASSESSING COSTS, INVESTMENT REQUIREMENTS, AND POLICY IMPLICATIONS
Sayanti Das **Assist. Prof. Dr. Monalisa Halder** **Dr. Jinia Datta** **Dibakar Das**	Abacus Institute of Engineering and Management, India	ADVERSE EFFECT OF CLIMATE CHANGE ON INDIAN ECONOMY
Fatima Ait Nouh **Hassan Khajmi** **Abdelhafid El Alaoui El Fels** **Chaymae Lachguer** **Saida Bahsine**	Cadi Ayyad University of Marrakech, Morocco Higher Institute of Nursing Professions and Health Technics, Morocco University Sultan Moulay Sliman, Morocco	ASSESSMENT OF THE DOSE IN DRINKING WATER RECEIVED BY INDIVIDUALS IN THE INDUSTRIAL REGION OF SAFI IN MOROCCO BY USING THE DSTN METHOD AND THE ICP-MS TECHNIQUE

04.12.2023 / Hall-5 / Online Session-1 / TSI Time - 10^{00}:12^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Assoc. Prof. Dr. Gökhan ÇAYLI

Authors	Affiliation	Presentation title
Yunus Emre GÜNDÜZ **Assist. Prof. Dr. Evrim ÖZRAHAT**	Kayseri University, Türkiye	COMPARISON OF THE FIRE PERFORMANCE OF AN INNOVATIVE INSULATION MATERIAL WITH CONVENTIONAL INSULATION MATERIALS
Mücahit Kaan YİĞİT **Res. Assist. Alperen EVCİMEN** **Assoc. Prof. Burak MARKAL**	Recep Tayyip Erdoğan University, Türkiye Karadeniz Technical University, Türkiye	EFFECTIVENESS ANALYSIS OF MINI-CHANNEL SHELL-AND-TUBE HEAT EXCHANGER
Assoc. Prof. Dr. Gökhan ÇAYLI	Istanbul University-Cerrahpaşa, Türkiye	PRODUCTION OF ENERGY EFFICIENT BUILDING ELEMENTS FROM RENEWABLE RESOURCES
Assoc. Prof. Dr. Gökhan ÇAYLI	Istanbul University-Cerrahpaşa, Türkiye	SYNTHESIS OF MONOGLYCERIDES VIA A NEW ENERGY-EFFICIENT METHOD
Mustafa GENCAY **Assist. Prof. Dr. Altug BOZKURT** **Lect. Dr. Ersan Omer YUZER**	Yıldız Teknik University, Türkiye Hakkari University, Türkiye	ENERGY EFFICIENCY AND GREEN TRANSFORMATION: AN EXAMPLE OF AN INDUSTRIAL FACILITY
Assoc. Prof. Dr. Abdul Vahap KORKMAZ	Afyon Kocatepe University, Türkiye	EFFECT OF MAGNESIUM SLAG PRODUCED BY THERMOCHEMICAL REDUCTION ON GRINDING BEHAVIOR AND ENERGY EFFICIENCY
Assoc. Prof. Dr. Abdul Vahap KORKMAZ	Afyon Kocatepe University, Türkiye	GREEN TRANSFORMATION IN THE CEMENT INDUSTRY: THE ROLE OF ENERGY AND INNOVATION
Mehmet Erdinç ARDA **Dr. Berkan ZÖHRA**	Amasya University, Türkiye	ENERGY OPTIMIZATION IN MICROGRIDS WITH MICROGRID ADVISOR SOFTWARE

04.12.2023 / Hall-6 / Online Session-1 / TSI Time - 10^{00}:12^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Alina Amanzhol

Authors	Affiliation	Presentation title
Zahra Nait Abdellah **Mourad Keddam**	Université Mouloud Mammeri, Algeria	PLASMA PASTE-BORIDING OF AISI 316 STEEL: CHARACTERIZATION OF BORIDE LAYERS AND BORON ACTIVATION ENERGY CALCULATION
Soufiane Elhadfi **Jamal Chenouf** **Hassane Chadli** **Brahim Fakrach** **Abdelhai Rahmani** **Abdelali Rahmani**	Moulay Ismail University, Morocco	CONCEPTION OF NEW ORGANIC SOLAR CELLS BASED ON CARBON NANOTUBES: A DFT STUDY
Bianca Șuian **Sonia Amariei**	Ştefan cel Mare University, Romania	RESEARCH ON NEW BIODEGRADABLE PACKAGING FOR FOOD INDUSTRY
Issam Jilal **Omar Azougagh** **Soufian El Barkany**	Sidi Mohamed Ben Abdellah University, Morocco	DISSOLUTION MECHANISM OF CELLULOSE IN A BENZYLTRIETHYLAMMONIUM/UREA DEEP EUTECTIC SOLVENT (DES): DFT-QUANTUM MODELING, MOLECULAR DYNAMICS AND EXPERIMENTAL INVESTIGATION
Mohammed, Nadamau Shehu **Kabiru I. Musa** **Shehu I. Galoji**	Abubakar Tafawa Balewa University, Nigeria Bauchi State University Gadau, Nigeria	BIOMETRIC IDENTIFICATION USING EEG SIGNALS: A DEEP LEARNING APPROACH FOR FEATURE EXTRACTION AND CLASSIFICATION
Abdullahi Abubakar **James Tolulope O.** **Uzaomaka A. Ezafulukwe** **Ibitokun, T. V** **Ogundeji A.A** **Babayemi, W.A**	Kebbi State University of Science and Technology, Nigeria University of Nigeria Nsukka, Nigeria	MONTE CARLO SIMULATION TECHNIQUES ON EVALUATING THE EFFECT OF SAMPLE SIZE ON SIMPLE LINEAR REGRESSION
Fatima Shehu Tofa **Usman Mahmud**	Bayero University, Nigeria Al-Qalam University, Nigeria	FUNDUS IMAGE-BASED DETECTION FOR GLAUCOMA WITH U-NET AND VISION TRANSFORMER
Dr. Jyothi B Nair **Lekshmi C. Nair** **Dr. Manu M Joseph**	Christ University, India	TRACKING THE FOOTPRINTS OF BIO-MOLECULES: EXPLORING THE SERS TRAJECTORY

05.12.2023 / Hall-1 / Online Session-2 / TSI Time - 10^{00}:12^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Dr. Halil ÇEÇEN

Authors	Affiliation	Presentation title
Uğur Cem TÜRKER **Kerem AYDIN**	Ankara Hacı Bayram Veli University, Türkiye Sakarya University, Türkiye	RENEWABLE ENERGY CHOICE AND THE PUBLIC INTEREST: BENEFIT OF FUTURE GENERATIONS
Assist. Prof. Dr. Emine ERDEN KAYA	Amasya University, Türkiye	ENERGY CRISES AND THEIR EFFECTS ON GLOBAL POLITICS
Assist. Prof. Dr. Ali Kemal EYÜBOĞLU **Prof. Dr. Muharrem Kemal ÖZFIRAT**	Maltepe University, Türkiye Dokuz Eylül University, Türkiye	COMPARATIVE ANALYSIS OF OCCUPATIONAL SAFETY IN OFFSHORE WIND ENERGY AND OFFSHORE OIL AND GAS ENERGY FACILITIES
Hasan Can BERBER	Ondokuz Mayıs University, Türkiye	THE ROLE OF SUSTAINABLE TRANSPORTATION POLICIES IN COMBATING CLIMATE CHANGE
Selime Beyza KORUMAZ **Assoc. Prof. Dr. Levent YİĞİTTEPE**	Karamanoğlu Mehmetbey University, Türkiye	RUSSIA'S NUCLEAR ENERGY TARGETS IN THE CHANGING ENERGY SECURITY ENVIRONMENT: ROSATOM'S MIDDLE EAST APPLICATIONS
Dr. Halil ÇEÇEN	Nuh Naci Yazgan University, Türkiye	ASSESSMENT OF THE RENEWABLE ENERGY MIXES IN THE EUROPEAN UNION AND TÜRKİYE IN ACCORDANCE WITH THE STATISTICS OF THE INTERNATIONAL RENEWABLE ENERGY AGENCY (IRENA)
Dr. Halil ÇEÇEN	Nuh Naci Yazgan University, Türkiye	REVIEW OF THE NEW RENEWABLE ENERGY SOURCES SUPPORT SCHEME ACCORDING TO THE TURKISH PRESIDENTIAL DECISION DATED ON 30 APRIL 2023 AND NUMBERED 7189 WITHIN THE FRAMEWORK OF ACQUIS COMMUNAUTAIRE

05.12.2023 / Hall-2 / Online Session-2 / TSI Time - 10^{00}:12^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Assist. Prof. Dr. Yakup KARAKOYUN

Authors	Affiliation	Presentation title
Hatice AYDIN **Prof. Dr. Muciz ÖZCAN**	Necmettin Erbakan University, Türkiye	FLEXIBLE CONNECTION OF DISTRIBUTED ENERGY RESOURCES TO THE GRID
Mustafa Sadeddin ERDENİZ **Yusuf HIZAL** **Murat GENÇAĞA** **Assoc. Prof. Dr. Ahmet FEYZİOĞLU**	EMELEC, Türkiye Marmara Unıversıty, Türkiye	DEVELOPMENT OF PD SENSOR FOR MEDIUM VOLTAGE CABLES
Berkay AYTÜRK **Res. Assist. Seyda ÖZBEKTAŞ** **Assoc. Prof. Dr. Bilal SUNGUR**	Samsun University, Türkiye Ondokuz Mayıs University, Türkiye	EXPERIMENTAL INVESTIGATION OF THE POTENTIAL OF THERMOELECTRIC GENERATORS WITH DIFFERENT POWERS
Res. Assist. Seyda ÖZBEKTAŞ **Assoc. Prof. Dr. Bilal SUNGUR** **Assoc. Prof. Dr. Alırıza KALELİ**	Ondokuz Mayıs University, Türkiye Samsun University, Türkiye	NUMERICAL INVESTIGATION OF THE THERMAL AND ELECTRICAL BEHAVIOR OF A CYLINDRICAL LITHIUM-ION BATTERY AT DIFFERENT DISCHARGE RATES
Fatih ÖNDER **Prof. Dr. Ünal KURT**	Amasya University, Türkiye	EVALUATION OF THE EFFECTS OF DISTRIBUTED GENERATION FACILITIES ON DISTRIBUTION NETWORKS
Assist. Prof. Dr. Yakup KARAKOYUN	Van Yuzuncu Yil University, Türkiye	A COMPARATIVE ANALYSIS ON THE EFFECT OF PRECIPITATION ON THE ENERGY PRODUCTION OF HYDROPOWER PLANTS
Assist. Prof. Dr. Berdan ULAŞ	Van Yuzuncu Yil University, Türkiye	SYNTHESIS AND CHARACTERIZATION OF $Pd_xNb_{(100-x)}$/CNT ANODE CATALYSTS FOR ETHYLENE GLYCOL ELECTROOXIDATION

05.12.2023 / Hall-3 / Online Session-2 / TSI Time - 10^{00}:12^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Dr. Stanislaw Strzelecki

Authors	Affiliation	Presentation title
Assist. Prof. Dr. Mete ÖZBALTAN **Lect. Mehmet KURUCAN**	Erzurum Technical University, Türkiye Ardahan University, Türkiye	POWER-AWARE RECONFIGURATION MANAGER FOR SMARTPHONES
Koray ALIN **Assist. Prof. Dr. İsmail TEMİZ**	Marmara University, Türkiye	PREDICTIVE MAINTENANCE APPLICATION ON PIPELINES USING ARTIFICIAL INTELLIGENCE MODEL
Ahlem CHEBEL **Abdelouahab BENRETEM** **Ivan DOBREV**	Badji-Mokhtar-Annaba University, Algeria Arts et Métiers-Paris Tech, France	INTEGRATION OF FUZZY LOGIC CONTROL IN THE MODELING OF A WIND ENERGY CONVERSION SYSTEM
Dr. Stanislaw Strzelecki	Lodz University of Technology, Poland	FRICTION LOSS GENERATED IN MULTILOBE AND TILTING – PAD JOURNAL BEARINGS
Dr. Lahyani Houda **Dr. Akourri Omar**	Abdelmalek Essaâdi University, Morocco	THE FLEXIBILITY EVALUATION IN THE ASSEMBLY WORKSHOP OF A TERMINAL AUTOMOTIVE FACTORY
Eren Anıl SEZER **Rumeysa ŞAHİN** **Mehmet SİNCAR** **Dr. Mustafa ÖZDEN** **Asst. Prof. Halil Hakan AÇIKEL** **Prof. Dr. Mustafa Serdar GENÇ**	Erciyes University, Türkiye	EFFECT OF AIRFOIL THICKNESS ON FLOW OVER THE SYMMETRIC AIRFOILS: PART II-NUMERICAL ANALYSIS

05.12.2023 / Hall-4 / Online Session-2 / TSI Time - 10^{00}:12^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Dr. Zakaria LAFDAILI

Authors	Affiliation	Presentation title
Dr. Zakaria LAFDAILI **Hamid MOUNIR** **Khalid EL ATIFE** **Sakina El-Hamdani**	Mohammed V University, Morocco Ibn Zohr University, Morocco	USE OF A REFINED MESH WITH TWO NON-CONFORMING BLOCKS TO NUMERICALLY STUDY THE EFFECT OF THE GROOVES OF A VERTICAL WALL IN A DIFFERENTIALLY HEATED SQUARE CAVITY ON THE NATURAL CONVECTION OF A NANO-FLUID
Khalid Elatife **Abdellatif El Marjani** **Zakaria Lafdaili**	Mohammed V University in Rabat, Morocco	EVALUATION OF THE EFFECT OF BLADE PROFILES ON THE PERFORMANCE OF RADIAL IMPULSE TURBINES FOR WAVE ENERGY CONVERSION
Dr. Hammouti Marwane **El Haim Mohamed**	Abdelmalek Essaâdi University, Morocco	FORECASTING LAND SHIFT RISKS WITH MAPPING IN MOROCCO'S MIDDLE RIF.
Dr. Swarupa Rani gurram **Dr. Mohammed Afzal Azam**	Vikas College of Pharmaceutical Sciences, India	EVOLUTION OF ENERGY SYSTEMS: PATTERNS AND MECHANISMS
Shehu Ahmadu Nadamau **Ibrahim Mustapha**	Ahmadu Bello University, Nigeria College of Health Science and Technology, Nigeria	CURRENT ADVANCES IN BIOENERGY PRODUCTION HARNESSING THE POWER OF NATURE FOR SUSTAINABLE ENERGY
Bijender Singh **Anu** **Davender Singh**	Central University of Haryana, India Maharshi Dayanand University, India RPS Degree College, India	ALKALINE PRETREATMENT AND ENZYMATIC SACCHARIFICATION OF RICE STRAW FOR THE PRODUCTION OF BIOETHANOL
Hooman Fatoorehchi **Seyed Amirreza Babaei** **Niloofar Arabi**	University of Tehran, Iran	STABILITY ANALYSIS OF A HYDRO POWER PLANT BASED ON BERKOWITZ ALGORITHM AND ROUTH-HURWITZ CRITERION
Krimech, A. **Cherifi,O.** **Hejjaj,A.** **Mugani,R.** **Ouazzani,N.** **Kerner,M.** **Oudra, B.** **Mandi,L.**	Cadi Ayyad University, Morocco SSC Strategic Science Consult GmbH, Germany	BIOMASS PRODUCTION OF Chlorella sorokiniana UCAM 001 IN FLAT-PLATE PHOTOBIOREACTORS UNDER THE ARID CLIMATE OF MOROCCO

05.12.2023 / Hall-5 / Online Session-2 / TSI Time - 10^{00}:12^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Dr. Ashok Kumar Atri

Authors	Affiliation	Presentation title
Zanaira Batool **Shanza Abbas**	Comsats University Islamabad, Pakistan	ENERGY JUSTICE: BRIDGING GAPS IN ACCESS, DISTRIBUTION, AND ENVIRONMENTAL IMPACTS
Dr. Ashok Kumar Atri	RKSD College, India	RISING ENERGY DEMAND IMPELS INDIA TO LOOK FOR SUPPLY ALTERNATE
Ayushi Singh **Sparsh Yadav** **Nalinesh Singh** **Neha** **Yash Prarup**	Galgotias University, India	DISPUTE RESOLUTION MECHANISMS IN CROSS-BORDER ENERGY AGREEMENTS
Ganya, Adamu Hauni **Dauda, Hauwa** **Ango, Monica** **Asabe Ibrahim**	Usmanu Danfodiyo University, Nigeria Shehu Shagari University of Education Sokoto, Nigeria Federal University of Agriculture, Nigeria	ENERGY-SAVING MECHANISMS FOR EVALUATING EFFICIENCY IMPROVEMENT AND LOSSES REDUCTION SCENARIOS IN THE THERMAL POWER PLANTS SECTOR OF NIGERIA
Alya Nisrina Huwaida **Ismahtul Hanifah** **Hendri Hermawan ADİNUGRAHA**	UIN K.H. Abdurrahman Wahid Pekalongan, Indonesia	ELECTRIC ENERGY CONSUMPTION BEHAVIOR VIEWED FROM AN ISLAMIC ECONOMIC PERSPECTIVE
Chakib EL FISSI	Hassan II University of Casablanca, Morocco	ENERGY EFFICIENCY AND ENERGY STRATEGIES
Thomas, Ekaobong Akan	Akwa Ibom State Polytechnic, Nigeria	AN APPRAISAL OF THE LEGAL AND REGULATORY FRAMEWORK FOR RENEWABLE ENERGY IN NIGERIA
Joseph Chisom Okoye **Chidi U. Arubalueze**	University of Nigeria, Nigeria	ENERGY TRANSITION IN AGRICULTURE: ASSESSING THE IMPACT OF RENEWABLE TECHNOLOGIES ON FARMING PRACTICES WORLDWIDE
Ayushi Singh **Sparsh Yadav** **Nalinesh Singh**	Galgotias University, India	NAVIGATING LEGAL COMPLEXITIES: CHALLENGES IN CORPORATE ENERGY PROCUREMENT

05.12.2023 / Hall-6 / Online Session-2 / TSI Time - 10^{00}:12^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Samira Ontunch

Authors	Affiliation	Presentation title
Dr. BENCHEKROUN Marwa **Dr. BABA SLIMANE Nour El Houda**	University Saad Dahleb of Blida-1, Algeria High School of Architecture and Urban Planning, Algeria	ADVANCING SUSTAINABLE DEVELOPMENT: BUILDING CERTIFICATION INITIATIVES IN ALGERIA
Dr. BABA SLIMANE Nour El Houda **Dr. BENCHEKROUN Marwa**	High School of Architecture and Urban Planning (EPAU), Algeria University Saad Dahleb of Blida-1-, Algeria	ENHANCING ENERGY EFFICIENCY THROUGH BIOPHILIC ARCHITECTURE
Salim Mesbahi **Samiha Djemai**	Ferhat Abbas University, Algeria	GREEN SOLUTIONS FOR COOLING: TOWARDS SUSTAINABLE AND ENERGY- EFFICIENT COOLING SYSTEMS
Samiha Djemai **Salim Mesbahi**	Ferhat Abbas University, Algeria	HARNESSING SOLAR ENERGY FOR COOLING IN BUILDINGS: PRINCIPLES, POTENTIAL BENEFITS, AND INTEGRATION STRATEGIES
Zineb MOUJOUD **Abdeslam EL BOUARI** **Omar TANANE**	Hassan II University of Casablanca, Morocco	NATURAL FIBER-BASED GEOPOLYMER COMPOSITES WITH LOW THERMAL CONDUCTIVITY FOR ENERGYEFFICIENT BUILDINGS
Bala Balarabe **Andy Anderson Bery** **Umar Mahmood**	Ahmadu Bello University, Nigeria	APPLICATION OF ELECTRICAL RESISTIVTY METHOD FOR PRE- CONSTRUCTION ASSESSMENT

05.12.2023 / Hall-1 / Online Session-3 / TSI Time - 12^{30}:14^{30}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Prof. Dr. Cemil ALKAN

Authors	Affiliation	Presentation title
Assist. Prof. Dr. Alper UĞUR **Assoc. Prof. Dr. İlker AVAN**	Eskişehir Technical University, Türkiye	TRIBOFILM FORMATION OF ZNS NANOPARTICLES MODIFIED WITH LIPOPHILIC ORGANIC MOLECULE
Zehra EROL **Prof. Dr. Meryem EVECEN**	Amasya University, Türkiye	EFFECTS OF MONO-FLOR(CHLORINE)-SUBSTITUTION ON THE STRUCTURAL AND NON-LINEAR OPTICAL PROPERTIES OF POLY(3-HEXYLTHIOPHENE-2,5- DIYL) FOR SOLAR CELL APPLICATIONS
Prof. Dr. Nuray TOKGÖZ **Dr. Emre AVUNDUK**	Istanbul University Cerrahpaşa, Türkiye Istanbul Technical University, Türkiye	ENERGY AVAILABILITY ANALYSIS OF TRAKYA REGION COALS WITH NEW GENERATION TECHNOLOGIES
Usman Ahmed Kehinde **Bello Yusuf Ayoola** **Hassan Yusuf Adigun** **Aliyu Yahaya**	Ahmadu Bello University, Nigeria The Air Force Institute of Technology (AFIT), Nigeria	EVALUATION OF GEOTHERMAL ENERGY RESOURCE POTENTIAL IN NORTH - EASTERN NIGERIA USING SPECTRAL ANALYSIS OF AEROMAGNETIC DATA
Zeba Ali Mumtaj **Abdul Rahman Khan** **Saimah Khan**	Integral University, India	ECO-FRIENDLY WASTEWATER TREATMENT TECHNIQUES IN CONSTRUCTED WETLANDS THAT PROMOTE ENERGY CONSERVATION
Lect. Dr. Nazan GÖKŞEN TOSUN **Prof. Dr. Cemil ALKAN**	Tokat Gaziosmanpaşa University, Türkiye	SYNTHESIS and CHARACTERIZATION OF A P(VCL-co-AA) COPOLYMER AS THERMOTROPIC POLYMER
Lect. Dr. Nazan GÖKŞEN TOSUN **Prof. Dr. Cemil ALKAN**	Tokat Gaziosmanpaşa University, Türkiye	1,4-PHENYLENE DISTEARYLAMIDE AS A NOVEL PHASE CHANGE MATERIAL FOR THERMAL ENERGY STORAGE

05.12.2023 / Hall-2 / Online Session-3 / TSI Time - 12^{30}:14^{30}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Res. Assist. Gökhan YÜKSEK

Authors	Affiliation	Presentation title
Assoc. Prof. Dr. Mehmet Uğraş CUMA **Assoc. Prof. Dr. Murat Mustafa SAVRUN**	Çukurova University, Türkiye Adana Alparslan Türkeş Science and Technology University, Türkiye	EXAMINING THE MULTIPLE ELECTRIC VEHICLE PERFORMANCE OF BATTERY BUFFERED DC FAST CHARGER
Res. Assist. Gökhan YÜKSEK **Assoc. Prof. Dr. Alkan ALKAYA**	Mersin University, Türkiye	A NOVEL APPROACH TO EXTEND THE BATTERY LIFE BY STATE OF HEALTH MANAGEMENT CONSIDERING THE CELL TEMPERATURE
Res. Assist. Gökhan YÜKSEK **Assoc. Prof. Dr. Alkan ALKAYA**	Mersin University, Türkiye	COMPARATIVE ANALYSIS OF DC-DC CONVERTER TOPOLOGIES IN BATTERY-SUPERCAPACITOR HYBRID ENERGY SYSTEMS: A SIMULATION STUDY
Doughri Doha **Mehdaoui Boubker** **El Bouari Abdeslam**	University Hassan II of Casablanca, Morocco	EXPLORING Li4MSbO6 AS A POTENTIAL CANDIDATE FOR NEXT-GENERATION Li-Ion BATTERIES: STRUCTURAL AND ELECTRICAL CHARACTERISTICS
Kaoutar Moulakhnif **Hanane Ait Ousaleh** **Said Sair** **Youness Bouhaj** **Mohssine Ghazoui** **Abdessamad Faik** **Abdeslam El Bouari**	Hassan II University of Casablanca, Morocco Mohammed VI Polytechnic University, Morocco Sultan Moulay Slimane University, Morocco	ADSORBENT MATERIALS BASED-SALT HYDRATE FOR THERMOCHEMICAL ENERGY STORAGE
Madhavan Madheswaran **Shobana Babu** **Pandiaraja Duraisamy** **Prakash Periakaruppan**	Madurai Kamaraj University, India	THE COMPARISON OF THE LIFETIME ESTIMATION OF ELECTROCHEMICAL ENERGY STORAGE DEVICES USING STOCHASTIC DIFFERENTIAL EQUATIONS

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ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION:

Authors	Affiliation	Presentation title
Lect. Dr. Betül ŞAHİN	Trabzon University, Türkiye	PLANT BIOMASS POTENTIAL OF ELAZIĞ PROVINCE
Assist. Prof. Dr. Saliha ÖZARSLAN **Assist. Prof. Dr. Melih YILDIZ**	Amasya University, Türkiye Iğdır University, Türkiye	MODELING COMBUSTION OF BIOMASS TEA WASTE IN A VERTICAL FURNACE UNDER DIFFERENT EXCESS AIR RATIOS: A CFD ANALYSIS
Metehan KANYILMAZ **Prof. Dr. Sema YURDAKUL** **Assoc. Prof. Dr. Barış GUREL**	Süleyman Demirel University, Türkiye	INVESTIGATION OF TOREFICATION PARAMETERS OF ROSE PULP AND CHICKEN MANURE
Sultan FAAL **Assoc. Prof. Dr. Mehmet Sait İZGİ** **Assist. Prof. Dr. Erhan ONAT**	Siirt University, Türkiye Bitlis Eren University, Türkiye	SYNTHESIS OF CARBON QUANTUM DOTS BY SOLVOTHERMAL METHOD AND HYDROGEN PRODUCTION FROM THE HYDROLYSIS OF DIMETHYLAMINE BORANE
Assist. Prof. Dr. Erhan ONAT **Sultan FAAL** **Assoc. Prof. Dr. Mehmet Sait İZGİ**	Bitlis Eren University, Türkiye Siirt University, Türkiye	HYDROLYSIS AND KINETIC MECHANISM OF DIMETHYLAMINE BORANE USING NI NANOCATALYST OBTAINED VIA GREEN SYNTHESIS
Burhan Burak GENÇKAN **Assist. Prof. Dr. Ayetül GELEN**	Bursa Technical University, Türkiye	DESIGN and FABRICATION of a TEST STATION for VARIOUS FUEL CELLS
H. Benaali **A. Tahiri** **M. Naji** **S. bahhar**	Sidi Mohamed Ben Abdellah University, Morocco Choua¨ıb Doukkali University, Morocco	DFT-BASED FIRST-PRINCIPLES CALCULATIONS OF NEW KXH3 (X = Mn, Fe) HYDRIDE COMPOUNDS FOR HYDROGEN STORAGE APPLICATIONS
Assoc. Prof. Dr. Kassayeva Assylkanym Zhulamanovna **Savelkin Nikita Kirillovich**	Yessenov University, Kazakhstan	PRODUCTION OF GREEN HYDROGEN BY LOW-TEMPERATURE ELECTROLYSIS

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ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Prof. Dr. C. Slimani

Authors	Affiliation	Presentation title
Aniekan Essienubong Ikpe **Mfonobong Rivenus Asuquo** **Michael Okon Bassey**	Akwa Ibom State Polytechnic, Nigeria	POTENTIAL BENEFITS AND DRAWBACKS OF WASTE-TO-ENERGY CONVERSION: A REFLECTION ON THE ENVIRONMENTAL IMPACT, ECONOMIC VIABILITY AND SOCIAL IMPLICATIONS
Mohamed Farhaoui **Prof. Dr. C. Slimani**	Sidi Mohamed Ben Abdellah University, Morocco	EFFECTS OF GREEN BUILDING AND ENERGY SAVING OH HOUSING MARKET VALUATION
Oussama Hartal **Salah Souabi** **Abdelaziz Madinzi**	University Hassan II, Morocco	OPTIMIZATION OF THE COAGULATION-FLOCCULATION PROCESS FOR THE TREATMENT OF WASTEWATER FROM VEGETABLE OIL REFINERIES
Chaima Kahouadji **Tayeb Hocine** **Brahim Bouras** **Kamel Ismet Benabadji** **Oussama Bouras** **Amal Hocine**	University of Tlemcen, Algeria	APPLICATION OF A COPOLYMER TO WATER TREATMENT
Smart M. O. **Okumodi B. O.** **Bamigboye T. O.** **Ibironke O. H.** **Roberts A. E.**	Federal College of Forestry, Nigeria Forestry Research Institute of Nigeria, Nigeria University of Ibadan, Nigeria	ECOLOGICAL RISK ASSESSMENTS OF POTENTIALLY TOXIC ELEMENTS IN SOILS AROUND LAPITE DUMP SITE, AKINYELE LOCAL GOVERNMENT
Khadija Zidan **Laila Mandi** **Abdessamed Hejjaj** **Naaila Ouazzani** **Ali Assabbane**	Cadi Ayyad University, Morocco University Ibn Zohr, Morocco	SEASONAL EFFECTS ON THE EFFICIENCY OF A NEW HYBRID MULTI-SOIL-LAYERING ECO-FRIENDLY TECHNOLOGY FOR REMOVING POLLUTANTS FROM DOMESTIC WASTEWATER UNDER AN ARID CLIMATE

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ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Assoc. Prof. Dr. Tarik Touiss

Authors	Affiliation	Presentation title
Assoc. Prof. Dr. Tarik Touiss **Prof. Dr. Driss BRIA**	Mohamed Frist University, Morocco	DEFECTIVE PHOTONIC COMB-LIKE WAVEGUIDES STRUCTURE USING TRANSFER MATRIX METHOD
Assoc. Prof. Dr. Tarik Touiss **Prof. Dr. Driss BRIA**	Mohamed Frist University, Morocco	ANALYSIS OF PERIODIC CYLINDRICAL WAVEGUIDES FOR PHOTONIC FILTERING APPLICATIONS USING THE TRANSFER MATRIX METHOD
S. Bahhar **A. Jabar** **L. Bahmad** **S. Benyoussef** **A. Tahiri**	Chouaïb Doukkali University, Morocco Hassan II University of Casablanca, Morocco Mohammed V University, Morocco	COMPUTATIONAL STUDY OF STRUCTURAL, MAGNETIC, ELECTRONIC, OPTICAL, AND THERMOELECTRIC PROPERTIES OF QUATERNARY FULL-HEUSLER ALLOY FeCuMnSi
Bilal Merouane Turki **Haroun Righi** **Massaoud Caid** **Djamel Rached** **Youcef Rached** **Ahmed Arab Ait belkacem**	University of Sidi-Bel-Abbes, Algeria Universit´e Ahmed Ben Yahia El-Wancharisi Tissemsilt, Algeria	HETEROSTRUCTURES OF SEMI CONDUCTRICES
Abdelmoumen Ghilani **Amel Terki** **Ahmed Marouane Ghodbane** **Zakaria alili**	University of Biskra, Algeria	THE OPTIMAL DESIGN FOR GRID-CONNECTED PV SYSTEMS
S. Elmazouzi **H. Mabrak** **A. Salim** **I. Zerdani** **Y. Naimi**	Hassan II University of Casablanca, Morocco	OPTIMIZING ELECTRO-ACTIVE BIOFILM FORMATION FOR ENHANCED MICROBIAL FUEL CELL PERFORMANCE
Astitva Kumar Rao	Dr. B. R. Ambedkar National Law University, India	INTEGRATION OF RENEWABLE ENERGY SOURCES IN THE POWER GRID: CHALLENGES AND SOLUTIONS
Assist. Prof. Dr. Jogendra Kumar	G.B.Pant Institute of Engineering and Technology, India	SIMULATION PERFORMANCE ANALYSIS OF ROUTING PROTOCOLS USING ENERGY MODEL

05.12.2023 / Hall-6 / Online Session-3 / TSI Time - 12^{30}:14^{30}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Blerina Bylykbashi

Authors	Affiliation	Presentation title
Noor Nabi Shah	University of Engineering and Technology, Pakistan	A LEAST SQUARE-LAPLACE TRANSFORM METHOD FOR SOLVING VOLTERRA INTEGRAL EQUATION WITH HIGHLY OSCILLATORY BESSEL KERNELS
LAGRINI Ismail **TBATOU Taoufik** **BENCHEIKH Mohamed**	Hassan II University of Casablanca, Morocco	DOSIMETRIC OPTIMIZATION IN HIGH-DOSE RADIOTHERAPY: TECHNIQUES AND CHALLENGES
Mostafa RACHIK **Issam KHALOUFI** **Youssef BENFATAH** **Hamza BOUTAYEB** **Hassan LAARABI**	Hassan II University of Casablanca, Morocco	ON THE CONTROL OF THE FINAL SPEED FOR A CLASS OF FINITE-DIMENSIONAL LINEAR SYSTEMS: CONTROLLABILITY AND REGULATION
Dr. BRAKNI Oumaima **Dr. Amrouche Fethia** **Dr.Abdallah Mohammedi** **Prof. KERBOUA ZIARI Yasmina**	University of Science and Technology Houari Boumediene (USTHB), Algeria Centre de Développement des Énergies Renouvelables, Algeria University of Batna 2, Algeria	UNVEILING EFFICIENCY: CFD STUDY ON PEMFC PERFORMANCE VIA FLOW FIELD CHANNEL DESIGN WITH GAMBIT AND FLUENT FOR SUSTAINABLE ENERGY
Blerina Bylykbashi	University of Prishtina, Kosova	INCREASING PERFORMANCE OF PHOTOVOLTAIC SYSTEMS: A CASE STUDY KOSOVA

05.12.2023 / Hall-1 / Online Session-4 / TSI Time - 15^{00}:17^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Dr. Bukurije Hoxha

Authors	Affiliation	Presentation title
Jisike Oluchukwu Faith **Eje Ozoemena Emmanuel**	University of Nigeria, Nigeria	BIOMASS FOR BIOFUEL PRODUCTION AND ENERGY EFFICIENCY: CHALLENGES AND FUTURE PROSPECT
Vidya Padmakumar **Murugan Shanthakumar**	Bangalore University, India	AN EVALUATION OF THE ECOLOGICAL IMPACTS OF TIDAL POWER PLANTS ON MARINE BIODIVERSITY AND ECOSYSTEM SERVICES
Basma BENBOUYA **Hocine CHEGHIB** **Oussama TOUABA** **Meriem BEHIM**	Annaba University, Algeria Unit of research and development of renewable energy, Algeria	PARTIALLY SELF-CHARGING SOLAR VEHICLE
Bekir Bytyqi **Bukurije Hoxha**	University of Debrecen, Hungary University of Prishtina Hasan Prishtina, Kosovo	THE POSSIBILITY OF USING BIOMASS AS A SOURCE OF ENERGY, CASE OF KOSOVO
Kosovare Latifaj **Bukurije Hoxha**	University of Prishtina Hasan Prishtina, Kosovo	THE CONTRIBUTION OF WIND ENERGY TO ENERGY STABILITY IN KOSOVO
Prof. Vijay Kumar **Dr. Sunil Kumar**	Indira Gandhi University, India	STRUCTURAL MORPHOLOGY DEPENDENCE ON PERFORMANCE OF NATURAL DYE-SENSITIZED ZnO SOLAR CELLS
Oumaima Chajii **Younes Chemchame** **Abdeslam El Bouari**	Hassan II University of Casablanca, Morocco	APPLICATION OF A NATURAL DYE IN DYE-SENSITIZED SOLAR CELLS AND THEIR CHARACTERISTICS
Amina OUAHBI **Youness BOUHAJ** **Said SAIR** **Abdeslam EL BOUARI** **Omar TANANE**	Hassan II University of Casablanca, Morocco	HAP MODIFIED BY SPINEL $ZnAl_2O_4$ USED AS HETEROGENEOUS CATALYST FOR BIODIESEL SYNTHESIS
Badis Bakri **Hani Benguesmia** **Zied Driss**	University of M'sila, Algeria University of Sfax, Tunisia	STUDY OF A SOLAR AIR HEATER TEST BENCH PERFORMANCE

05.12.2023 / Hall-2 / Online Session-4 / TSI Time - 15^{00}:17^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Assoc. Prof. Dr. Mustafa OZCAN

Authors	Affiliation	Presentation title
Res. Assist. Rana UZUN **Assoc. Prof. Dr. Seher GÜZELÇOBAN MAYUK** **Assist. Prof. Dr. Elif ÖZER YÜKSEL**	Gebze Technical University, Türkiye	CURRENT PRACTICES IN ENERGY-EFFICIENT FACADE DESIGN: DOUBLE SKIN FACADE SYSTEMS AND PHASE CHANGE MATERIALS
Lect. Mustafa Serhan UNLUTURK **Prof. Dr. Turkan GOKSAL OZBALTA**	Balikesir University, Türkiye Ege University, Türkiye	LITERATURE REVIEW ON AIR TIGHTNESS PARAMETER IN BUILDING ENVELOPE
Assoc. Prof. Dr. Mustafa OZCAN	Kocaeli University, Türkiye	DECARBONIZATION OF TRANSPORTATION AND BUILDING SECTORS IN TURKEY
Zehra Nur SOYDABAŞ AYDOĞAN **Assoc. Prof. Dr. Seher GÜZELÇOBAN MAYUK**	Gebze Technical University, Türkiye	EXAMINATION OF PASSIVE AIR CONDITIONING METHODS IN TERMS OF ENERGY EFFECTIVENESS
Yasemin GÜNGÖR **Ökem ÇELEM** **Faruk TELEMCİOĞLU**	Union of Energy Cities, Türkiye	RENEWABLE ENERGY AND COOPERATION BETWEEN MUNICIPALITIES: THE CASE OF THE UNION OF ENERGY CITIES
Sushrut Patankar **Raju Kumar Swami** **Sameer Nanivadekar**	Pacific Academy of Higher Education and Research University, India A P Shah Institute of Technology, India	EMERGING TRENDS IN SMART BUILDING ENERGY MANAGEMENT: A COMPREHENSIVE REVIEW OF AI, IoT, AND SUSTAINABILITY ADVANCES
Sinan GÜNEŞ **Prof. Dr. Mustafa TOMBUL**	Ankara University, Türkiye	GREY BOX APPROACH FOR ENERGY CONSUMPTION FORECASTING IN UNIVERSITY CAMPUS BUILDINGS

05.12.2023 / Hall-3 / Online Session-4 / TSI Time - 15^{00}:17^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Assist. Prof. Dr. Aykut Fatih GÜVEN

Authors	Affiliation	Presentation title
Assist. Prof. Dr. Mahmut KAPLAN	Gaziantep University, Türkiye	PERFORMANCE IMPROVEMENT OF PEMFC BASED ON REDUCING SIZE OF THE SQUARE FLOW CHANNEL: A 3D CFD APPROACH
Res. Assist. Emine İŞİN **Assoc. Prof. Dr. Nurettin ÇETİNKAYA**	Konya Technical University, Türkiye	DETERMINATION OF OPTIMUM DC/AC RATIO FOR PV POWER PLANTS USING ARTIFICIAL INTELLIGENCE
Assist. Prof. Dr. Gökhan KEVEN	Nevşehir Hacı Bektaş Veli University, Türkiye	REDUCED HARMONICS IN A SEVEN LEVEL ASYMMETRIC MULTILEVEL INVERTER WITH APERIODIC DC SOURCES
Assist. Prof. Dr. Aykut Fatih GÜVEN	Yalova University, Türkiye	CONTROL and COMPARISON of A TIME-DELAYED SYSTEM USING PD, 2DOFPD, and FOPD CONTROLLER
Fella BOUCETTA **Mohamed Toufik BENCHOUIA** **Mohamed BECHERIF**	University Mohamed Khider Biskra, Algeria University UTBM, Algeria	CONTROL OF INDUCTION MOTOR USING FUZZY LOGIC APPROACH SIMULATION AND EXPERIMENTAL RESULTS
Ben O. Johnson	Federal University, Nigeria	PREDICTION OF THE ELECTRONIC TRANSITIONS OF BENZENE USING THE CHARACTER TABLE AND THE CONJUGACY CLASSES OF THE DIRECT PRODUCT OF PAIR OF DIHEDRAL GROUPS
Assoc. Prof. Dr. R. Boussetta **Dr. O. Mommadi** **Prof. A. EL-Moussaouy** **Prof. A. EL-Miad Kerkour**	University Mohamed I, Morocco	THE EFFECT FIELD ELECTRIC ON DIAMAGNETIC SUSCEPTIBILITY IN A GAAS TOROIDALE QUANTUM DOT
Assoc. Prof. Dr. R. Boussetta **Dr. O. Mommadi** **Prof. A. EL-Moussaouy** **Prof. A. EL-Miad Kerkour**	University Mohamed I, Morocco	THE IMPACT OF GEOMETRICAL CONFINEMENT AND EXTERNALLY APPLIED ELECTRIC AND MAGNETIC FIELDS ON THE ELECTRONIC ENERGY LEVELS IN A GAAS QUARTER TORUS QUANTUM DOT

05.12.2023 / Hall-4 / Online Session-4 / TSI Time - 15^{00}:17^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Dr. Sándor Földvári

Authors	Affiliation	Presentation title
Maciej Śniegowski	University of Szczecin, Poland	THE CHALLENGES OF THE HEAT PRODUCTION IN THE FRAME OF SUSTAINABLE EU DEVELOPMENT STRATEGY
Andréa Silva AZEVEDO **Luciano Sergio HOCEVAR** **Carine Tondo ALVES** **Jadiel dos Santos PEREIRA** **Gabrielly de Moura BEZERRA** **Maria Cândida Arrais de Miranda MOUSINHO** **Silvio Alexandre Beisl VİEİRA DE MELO**	Federal University of Bahia, Brazil Federal Institute of Bahia, Brazil Federal University of Recôncavo da Bahia, Brazil	ENERGY POVERTY IN THE ERA OF GLOBALIZATION: BRAZIL, CHINA AND INDIA
Hamid FARRICHA	Hassan II University of Casablanca, Morocco	ENERGY CHALLENGES IN WEST AFRICA
Syeda Nada Qadri **Rukhsar Khan**	Aligarh Muslim University, India	POWER STRUGGLES: ANALYZING THE GEOPOLITICS OF RENEWABLE ENERGY TRANSITION
Rukhsar Khan **Syeda Nada Qadri**	Aligarh Muslim University, India	FROM OIL DISCOVERY TO ENERGY HUB: TRACING THE HISTORICAL EVOLUTION OF GULF STATES' FUEL ECONOMIES
Rosario Marrapodi **Stefania Mele** **Caterina Galdiero** **Cecilia Maltempo**	Univerity of Campania Luigi Vanvitelli, Italy University of Salerno, Italy	EXPLORING SMART WORK'S IMPACT ON SUSTAINABILITY: A BIBLIOMETRIC ANALYSIS
Sri Padma Kanta Mishra **Assist. Prof. Deepak Bansal**	Indian Institute of Finance, India	ETHICAL ISSUES IN GLOBAL OIL PRICING AND ITS IMPACT ON EXCHANGE RATES AND STOCK MARKETS UNDER UNCERTAINTY
Dr. Aderinsola E. Kayode	Durban University of Technology, South Africa	EXPLORING APPROACHES IN HIGHER EDUCATION TO INTEGRATE ENERGY SUSTAINABILITY (A REVIEW)
Dr. Sándor Földvári	Debrecen University, Hungary	ENERGY SUPPLY FOR TÜRKIYE: OIL AND GAS IN UKRAINE UNDER THE BLACK SEA

05.12.2023 / Hall-5 / Online Session-4 / TSI Time - 15^{00}:17^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Samira Ontunch

Authors	Affiliation	Presentation title
Talha Mashhood **Dr. Muhammad Ibrahim** **Dr. Akbar Ali**	Government College University Faisalabad, Pakistan	SYNTHESIS AND BIOLOGICAL SCREENING OF HYDRAZONES USING ISOLATED CHOLIC ACID
Y.Didi **M.Belhajji** **A.Rjeb** **A.Tahiri** **M.Naji** **S.Bahhar**	Sidi Mohamed Ben Abdellah University, Morocco Chouaib Doukkali University, Morocco	BASED ON THE CALCULATION OF THE STRUCTURAL, MECHANICAL, OPTICAL, AND ELECTRONIC PROPERTIES OF THE OXIDE PEROVSKITE XBkO3 (X = Pb, Ra,Sr): A DFT STUDY
Prof. Dr. Abbas Khan **Ubaid Ur Rahman** **Asad Ullah** **Rashid Nawaz**	Abdul Wali Khan University Mardan, Pakistan	SYNTHESIS AND CHARACTERIZATION OF Zn DECORATED GRAPHENE OXIDE FOR ENHANCE PHOTOCATALYTIC APPLICATION
Wali Muhammad **Prof. Dr. Abbas Khan** **Dr. Sajjad Hussain**	Abdul Wali Khan University Mardan, Pakistan Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Pakistan	IMPROVING PHOTOCATALYTIC EFFICIENCY OF GRAPHATIC CARBON NITRIDE NANOCOMPOSITES BASED ON DOUBLE Z-SCHEME HETEROJUNCTIONS
Ouahiba Mrajji **Abdeslam EL Bouari** **Omar Cherkaoui**	Hassan II University of Casablanca, Morocco Higher School of Textile and clothing Industries, Morocco	NUMERICAL INVESTIGATION OF ECO-FRIENDLY MATERIALS FOR BUILDING ENVELOPE
Roguai Sabrina **Djelloul Abdelkader**	Abbes Laghrour University, Algeria	STRUCTURAL, OPTICAL, AND ELECTRICAL PROPERTIES OF 4%Co-SnO_2 FilMS BY USP METHOD
Derrar Oum hani **Djelloul Abdelkader**	Larbi Tbessi University, Algeria HD CRTSE, Algeria	STUDY OF THE MORPHOLOGICAL, STRUCTURAL AND OPTICAL PROPERTIES OF THIN LAYERS CZTS FOR PHOTOVOLTAIC APPLICATIONS
Osamah Ihsan Ali **Taha Hussein Mohammed**	University of Pannonia, Hungary University of Babylon, Iraq	MECHANICAL CHARACTERIZATION OF ADVANCED CHEMICAL VAPOR DEPOSITION COATINGS FOR CUTTING TOOL APPLICATIONS

05.12.2023 / Hall-6 / Online Session-4 / TSI Time - 15^{00}:17^{00}

ZOOM ID: 833 1287 1999 / PASSCODE: 100100

HEAD OF SESSION: Samira Ontunch

Authors	Affiliation	Presentation title
Ülkü KÖSE	Izmır Bakırçay University, Türkiye	STUDIES IN THE FIELD OF CARBON TRADE AND ENERGY LAW
Yasemin SELÇUK **Prof. Dr. Ebru Vesile ÖCALIR**	Gazi Unıversıty, Türkiye	BICYCLE TRANSPORTATION, URBAN PLANNING AND ENERGY EFFICIENCY, BIBLIOMETRIC ANALYSIS STUDY
Fikret KAYA **Assist. Prof. Onur AKAR**	Marmara Unıversıty, Türkiye	DEVELOPMENTS IN OFF-GRID ON-BOARD PORTABLE ELECTRIC VEHICLE CHARGING STATION
Seda Nur BOZKURT **Assoc. Prof. Dr. Selda KAPLAN ULUSOY**	Erciyes University, Türkiye	DATA-BASED MODELS FOR REMAINING USEFUL LIFE ESTIMATION OF TURBOFAN ENGINES -A REVIEW
Esma YILDIRIM **Assoc. Prof. Dr. Atilla DÖNÜK**	Aydın Adnan Menderes University, Türkiye	ENERGY EFFICIENCY PRACTICES IN PUBLIC HOSPITALS
Ali BEYKONT **Res. Assist. Sinem KESKIN** **Prof. Dr. Mustafa Serdar GENÇ**	Erciyes University, Türkiye	ANALYSIS OF THE WIND LOAD ON THE BUILDING IN TURBULENT FLOW IN OPENFOAM

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TÜRKİYE İLLERİNİN ENERJİ İHTİYAÇLARINA GÖRE MAKİNE ÖĞRENMESİ YÖNTEMLERİYLE ANALİZİ

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ÖZET

Günlük hayatın sekteye uğramadan devam edebilmesi için enerji zorunlu bir ihtiyaçtır. Ülkelerin üretim yapabilmeleri ve dolayısıyla ekonomik olarak kalkınabilmeleri için temel bir kaynak olan enerji, ülkelerin dışa bağımlılıklarını ve refah düzeylerini de doğrudan belirler. Küreselleşme, hızla gelişen teknoloji, artan nüfus vb. durumlar diğer tükenebilir kaynaklar gibi enerji kaynaklarını da etkilemiştir. Tüm dünya ülkeleri gibi ülkemiz için de enerji kaynaklarının ne kadar önemli bir konu olduğu bilinen bir gerçektir. Türkiye gibi büyük ve çeşitlilik gösteren bir ülkede enerji ihtiyacı için genel bir analiz yerine bölgelerin sosyoekonomik özelliklerine dayalı analizler, daha etkili ve hedefe yönelik politika oluşturma süreçlerine katkıda bulunabilir. Bu çalışmada, Türkiye'nin illerinin enerji ihtiyacına göre sosyoekonomik özellikler çerçevesinde kümelenmesi konusuna odaklanılmıştır. Kümeleme ve sınıflandırma yöntemleri kullanılarak farklı bölgeler arasındaki benzerlikler ve farklılıklar ortaya konmuş, bölgesel kalkınma planlamasında ve kaynakların etkin kullanımında yol gösterici olmak amaçlanmıştır. Çalışmada öncelikle enerji ihtiyacını etkilediği düşünülen yirmi iki sosyoekonomik değişken belirlenerek veri ön işleme adımları gerçekleştirilmiştir. Ön işleme adımlarında iki kriter elenmiş ve veriler normalize edilmiştir. Sonrasında küme sayısı 4, 5, 6, 7, 8, 9 ve 10 olmak üzere K-ortalamalar yöntemiyle iller kümelenmiştir. Ardından, makine öğrenmesi yöntemlerinden K en yakın komşu (K-Nearest Neighbors - KNN) ve Destek Vektör Makineleri (Support Vector Machines - SVM) kullanılarak sınıflama hatası hesaplanmış ve böylece kümeleme başarısı analiz edilmiştir. Ayrıca sınıflandırma yöntemleri uygulanırken çapraz doğrulamalar yapılarak parametre optimizasyonu gerçekleştirilmiştir. Küme sayısı KNN yöntemine göre 4, SVM yöntemine göre ise 6 olarak tespit edilmiştir. İlerleyen çalışmada, illerin konumları ve yenilenebilir enerjiye dair kriterler de eklenerek çalışma geliştirilebilir. Buna göre her küme için uygun bir yenilenebilir enerji alternatifi önerilebilir.

Keywords: Enerji ihtiyacı, makine öğrenmesi, K-ortalamalar, K en yakın komşu (KNN), Destek Vektör Makineleri (SVM).

ANALYSIS OF TÜRKİYE'S PROVINCES BASED ON ENERGY NEEDS USING MACHINE LEARNING METHODS

ABSTRACT

In order for daily life to continue without disruption, energy is a necessary requirement. Energy, which is a fundamental resource for countries to be able to produce and consequently develop economically, also directly affects the dependency of countries on external sources and their levels of prosperity. Globalization, rapidly advancing technology, increasing population, and other factors have also impacted energy resources, just like other depletable resources. It is a well-known fact that energy resources are of great importance for our country, as well as for all countries around the world. In a large and diverse country like Türkiye, analyses based on the

socio-economic characteristics of regions, rather than a general analysis of energy needs, can contribute to more effective and targeted policy-making processes. This study focuses on clustering the provinces of Türkiye based on their socio-economic characteristics in relation to energy needs. By using clustering and classification methods, similarities and differences between different regions are identified, aiming to provide guidance in regional development planning and efficient resource utilization. In this study, twenty-two socio-economic variables believed to influence energy needs were identified, and data preprocessing steps were performed. In the preprocessing steps, two criteria were eliminated and the data were normalized. Subsequently, the provinces were clustered using the K-means method with cluster numbers of 4, 5, 6, 7, 8, 9, and 10. Then, classification errors were calculated using the K-Nearest Neighbors (KNN) and Support Vector Machines (SVM) machine learning methods, and thus, clustering success was analyzed. Additionally, cross-validations were conducted during the application of classification methods to perform parameter optimization. The cluster number was determined to be 4 for the KNN method and 6 for the SVM method. In future studies, the work can be enhanced by incorporating criteria related to the locations of provinces and renewable energy. Accordingly, suitable renewable energy alternatives can be proposed for each cluster.

Keywords: Energy requirement, machine learning, K-means, K-Nearest Neighbors (KNN), Support Vector Machines (SVM).

GİRİŞ

Enerji; ısınma ve aydınlatma gibi günlük ihtiyaçların yanı sıra üretim ve hizmet sektörlerinin devamı için gerekli en önemli kaynaklardan biridir. Hızla artan dünya nüfusu enerji kaynaklarına olan ihtiyacı ve yeni kaynak arayışlarını da arttırmıştır. Enerji ihtiyacı ülkelerin ekonomik özgürlüklerini, dışa bağımlılıklarını ve dolayısıyla refah ve kalkınma düzeylerini de doğrudan etkiler. Günümüzde tüm dünya ülkelerinin artan enerji ihtiyacını karşılamak için bir arayış içinde oldukları bilinen bir gerçektir (Güneş & Arslan, 2018).

Enerji kaynakları, yenilenemez (tükenebilir) ve yenilenebilir enerji kaynakları olarak sınıflandırılabilir. Yenilenemez enerji kaynakları doğada halen bulunmakla birlikte, ileride bir gün tükenecek enerji türlerine işaret etmektedir. Bunlar arasında yer alan ham petrol, taş kömürü, doğal gaz gibi kaynaklar doğadan doğrudan çıkarıldığından birincil enerji kaynakları olarak tanımlanabilir. Birincil enerji kaynaklarından üretilen diğer ürünler ise ikincil enerji kaynakları olarak ifade edilmektedir. Yenilenebilir enerji kaynakları ise kendi kendini yenilediğinden doğada tükenmeyecek olan güneş enerjisi, rüzgâr enerjisi, jeotermal enerji, hidroelektrik enerji, dalga enerjisi, biyokütle enerjisi gibi enerji türleridir. Yenilenebilir enerjiler henüz yenilenemez enerji kaynakları kadar kullanılamamaktadır. Ancak doğaya en az zarar veren enerji türleri olduğundan ve ülkelerin dışa bağımlılıklarını azaltacağından kullanımlarının giderek arttırılması oldukça önemlidir (Bekar, 2020).

Türkiye enerji ihtiyacını çoğunlukla ithalat yoluyla karşılayan bir ülkedir. Ayrıca enerji ihtiyacının önemli bir bölümünü de fosil yakıtlardan sağlamaktadır. Gerek ülke ekonomisi gerek fosil yakıtların çevreye verdiği zarar düşünüldüğünde ülkemizin yenilenebilir enerji kaynaklarına olan ihtiyacı açıktır. Ayrıca Türkiye; yıllık 1.527 kWh/m^2'lik toplam güneş enerjisi, sahip olduğu organik atık hacmi, değişik sıcaklıklarda jeotermal kaynakları ve Çanakkale Boğazı, Bozcaada, Gökçeada, Sinop, İnebolu, Samsun, Bandırma, Balıkesir gibi rüzgâr enerjisi bakımından oldukça avantajlı bölgeleriyle yenilenebilir enerji kaynakları ile ilgili önemli bir potansiyele sahiptir (Yılmaz & Can Öziç, 2018). Bu bakımdan ülkemiz için yenilenebilir enerji kullanımının artması mümkün ve önemlidir.

Türkiye jeolojik özellikleri bakımından çeşitlilik gösteren, üç farklı iklime ve farklı bitki örtülerine sahip bir ülkedir. Bunun yanı sıra sosyoekonomik bakımdan da farklılıklar göstermektedir. Coğrafi olarak 7 bölgeye ayrılmış olsa da aynı bölge içinde dahi değişiklikler gösterebilmektedir. Ayrıca İstanbul, Ankara, İzmir gibi yüksek nüfuslu ya da Kocaeli gibi sanayi bakımından zengin illeri bulundukları bölgelerden bağımsız olarak da ele alınabilir. Dolayısıyla Türkiye'nin farklı bölgelerinin enerji ihtiyacı da birbirinden farklıdır. Bu nedenle çalışmada, Türkiye'nin illerinin enerji ihtiyaçlarına göre sosyoekonomik özellikler çerçevesinde kümelenmesi konusuna odaklanılmıştır. Çalışmanın geliştirilerek hangi bölgelerde yenilebilir enerji yatırımlarına öncelik vermek gerektiğinin belirlenmesi, bölgesel kalkınma planlaması ve kaynakların etkin kullanımında yol gösterici olması amaçlanmıştır.

YÖNTEM

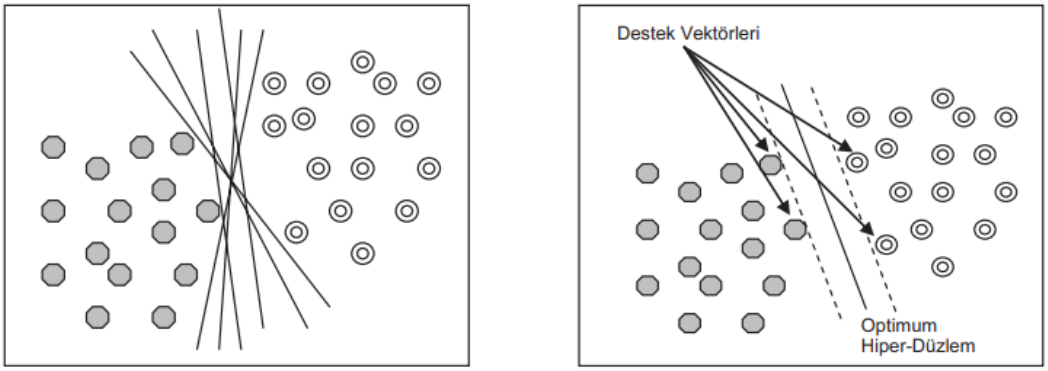
Bir probleme ait verilerin biriktirilmesi, bu verilerden anlamlı bilgi çıkarılabildiği ölçüde değerlidir. Veri analizi araçları kullanılarak veri kümeleri arasındaki gizli ilişkiler ortaya çıkarılabilmektedir. Bir problemi, problemle ait verileri kullanarak modelleyen algoritmalara genel olarak makine öğrenmesi denir ve bu amaçla geliştirilen pek çok yöntem mevcuttur. Bu yöntemlerin bir kısmı tahmin ve kestirim, bir kısmı kümeleme ve bir kısmı da sınıflandırma yapmak için kullanılır.

Makine öğrenmesi yöntemlerinde; denetimli, denetimsiz ve pekiştirmeli (takviyeli) olmak üzere üç tür öğrenme stratejisi bulunur. Denetimli öğrenmede her bir verinin etiketi mevcuttur. Bu etiketler, eğitim verileri ve test verileri kullanılarak girdi ve çıktılar arasında ilişki kurulur. Başka bir deyişle, sonuçları bilinen veri seti kullanılarak sonuçları bilinmeyen veri setine dair tahminlerde bulunulur. Denetimsiz öğrenmede ise veri etiketleri olmadığından tanıma ya da sınıflandırma yapılamaz. Bu yöntemler kümeleme, boyut indirgeme ya da olasılık yoğunluk tahmini gibi amaçlar için kullanılır (Atalay & Çelik, 2017). Çalışmada kullanılan makine öğrenmesi yöntemleri; kümeleme yöntemlerinden K-ortalamalar (K-means); sınıflama yöntemlerinden K en yakın komşu (KNN) ve Destek Vektör Makineleri (SVM)'dir. Alt başlıklarda bu yöntemlerden kısaca bahsedilmiştir.

Sınıflandırma

Sınıflandırma, daha karmaşık bilgilere ulaşmak için verileri önceden belirlenmiş sınıflara ayırmak ve/veya tahmin etmek için veri madenciliğini kullanan bir makine öğrenimi metodolojisidir. Aşağıda bazı sınıflandırma algoritmalarından bahsedilmiştir (Güleryüz, 2021).

Destek Vektör Makineleri (Support Vector Machines-SVM): SVM ilk olarak iki sınıflı doğrusal problemlerin sınıflandırılması için tasarlanmış, daha sonra ise çok sınıflı ve doğrusal olmayan verilerin sınıflandırılması için genelleştirilmiştir. SVM'nin çalışma prensibi, en uygun karar fonksiyonunu tahmin etmek veya başka bir deyişle, iki sınıfı en iyi şekilde birbirinden ayırabilen hiper-düzlemi tanımlamak üzerine kurulmuştur (Sasidharan, 2021).



Şekil 1. Destek vektör makineleri (SVM)

Şekil 1'de gösterildiği gibi, iki sınıflı verileri birbirinden ayırabilen pek çok hiper-düzlem çizilebilir. Ancak SVM'nin amacı, kendisine en yakın noktalar arasındaki uzaklığı maksimuma çıkaran bir hiper-düzlem bulmaktır. Optimum hiper-düzlemi belirlemek için bu düzleme paralel olan ve sınırları oluşturan iki hiper-düzlem belirlenmelidir. Bu hiper-düzlemleri oluşturan noktalar destek vektörleri olarak adlandırılır. Optimum hiper-düzlem sınırını maksimuma çıkarmak için *w* ifadesini minimuma indirmek gerekmektedir. Bu nedenle, en uygun hiper-düzlemi belirlemek için Denklem 1'de verilen sınırlı optimizasyon problemi çözülmelidir. Birçok durumda, verilerin doğrusal olarak ayrılması mümkün değildir. Bu durumda, eğitim verilerinin bir kısmının optimum hiper-düzlemin diğer tarafında kalmasıyla ortaya çıkan problem, pozitif bir yapay değişken (ξ) tanımlayarak çözülebilir. Sınırın maksimum hale getirilmesi ve yanlış sınıflandırma hatalarının minimum hale getirilmesi arasındaki denge Denklem 1'de gösterilen pozitif değerli *C* düzenleme parametresi tanımlanmasıyla kontrol edilebilir.

$$min\left[\frac{\|w\|^2}{2}+C.\sum_{i=1}^{r}\xi_i\right]$$
$$y_i(w.\varphi(x_i)+b)-1\geq 1-\xi_i \qquad (1)$$
$$\xi_i\geq 0\ ve\ i=1,\ldots.,N$$

Gerçek hayat problemlerinden genellikle veriler doğrusal olarak ayrılamaz. Böyle durumlarda veri, özellik uzayı olarak tanımlanan yüksek boyutlu bir uzayda görüntülenir. Böylece verilerin doğrusal olarak ayrımı yapılabilmekte ve sınıflar arasındaki hiper-düzlem belirlenebilmektedir. SVM'de doğrusal olmayan dönüşümler Denklem 2'de gösterilen bir Kernel fonksiyonu yardımıyla yapılabilir. Böylelikle veriler yüksek boyutta doğrusal olarak ayrılır. Literatürde çeşitli Kernel fonksiyonları geliştirilmiş olup çalışmada kullanılan Pearson VII (PUK) kerneli Denklem 3'te verilmiştir. Burada σ ve ω Pearson genişliği parametreleridir.

$$(x_i,x_j)=\varphi(x).\varphi(x_j) \qquad (2)$$

$$\frac{1}{\left[1+\left(\frac{2.\sqrt{\|x-y\|^2\sqrt{2^{(\frac{1}{\omega})}-1}}}{\sigma}\right)^2\right]^{\omega}} \qquad (3)$$

K-en yakın komşu (K-Nearest Neighbors- KNN): KNN basit ve etkin bir yöntem olarak klasik bir sınıflandırma algoritmasıdır. KNN yönteminin temel dayanak noktası, sorgunun sınıf etiketini eğitim setindeki en yakın komşularının sınıflarına göre belirlemektir. Diğer bir deyişle, sorguyu, k sayıdaki en yakın komşusu arasında en sık görünen sınıfa atayabilmektedir. (Tahtalı, 2020). Burada en yakın komşu sayısının doğru belirlenmesi önemlidir.

Kümeleme

Kümeleme analizi, bir çok değişkenli analiz tekniği olarak verileri gruplandırmada kullanılan bir yöntemdir. Kümeleme analizinin amacı, gruplanmamış verileri benzerliklerine göre sınıflandırmaktır. Bu analizde hedef, denetimsiz bir şekilde küme içindeki benzerliği maksimuma çıkarmak ve kümeler arasındaki benzerliği minimuma indirmektir. En popüler kümeleme yöntemlerden biri olan K-ortalamalar yöntemidir.

K-ortalamalar (K-means): Veri kümesini önceden belirlenmiş *k* sayıdaki ayrık alt kümeye ayıran yöntemdir. Bu algoritma, nesneleri yeni bir kümeye atanamayana kadar en yakın geçerli küme ortalamasına göre bir kümeye atar. Yöntemde küme sayısını önceden belirlemek zor ve iyi sonuç elde etmek için önemlidir (Wu, Peng, Lee, Leibnitz, & Xia, 2021). Algoritma adımları şu şekildedir:

1. X kümesinde rasgele *k* tane ağırlık merkezi noktası belirlenir.

2. X kümesinin elemanları, en yakın olduğu küme merkezine göre, ilgili kümelemeye atanarak *k* tane kümeleme elde edilir.

3. Oluşan kümelerin yeni ağırlık merkezi hesaplanır.

4. 2. ve 3. adımdaki işlemler ağırlık merkezleri değişmeyene kadar sürdürülür.

Algoritmada uzaklıklar belirlenirken genellikle Öklid uzaklığı tercih edilir.

BULGULAR

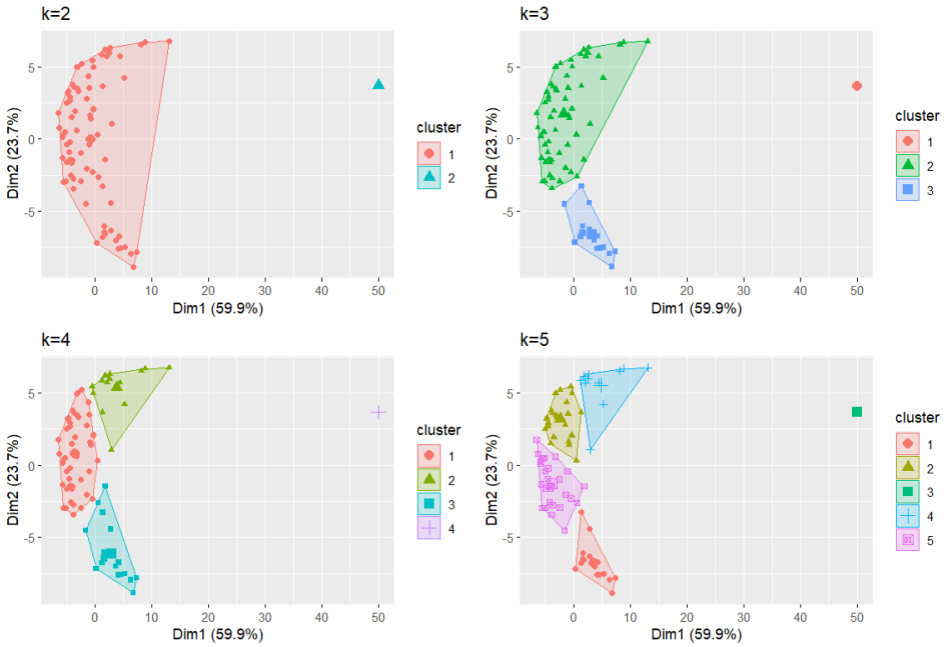
Çalışmada, Türkiye'nin illerinin enerji ihtiyacına göre sosyoekonomik özellikler çerçevesinde kümelenmesi için 22 sosyoekonomik değişken ele alınmış ve Tablo 1'de gösterilmiştir.

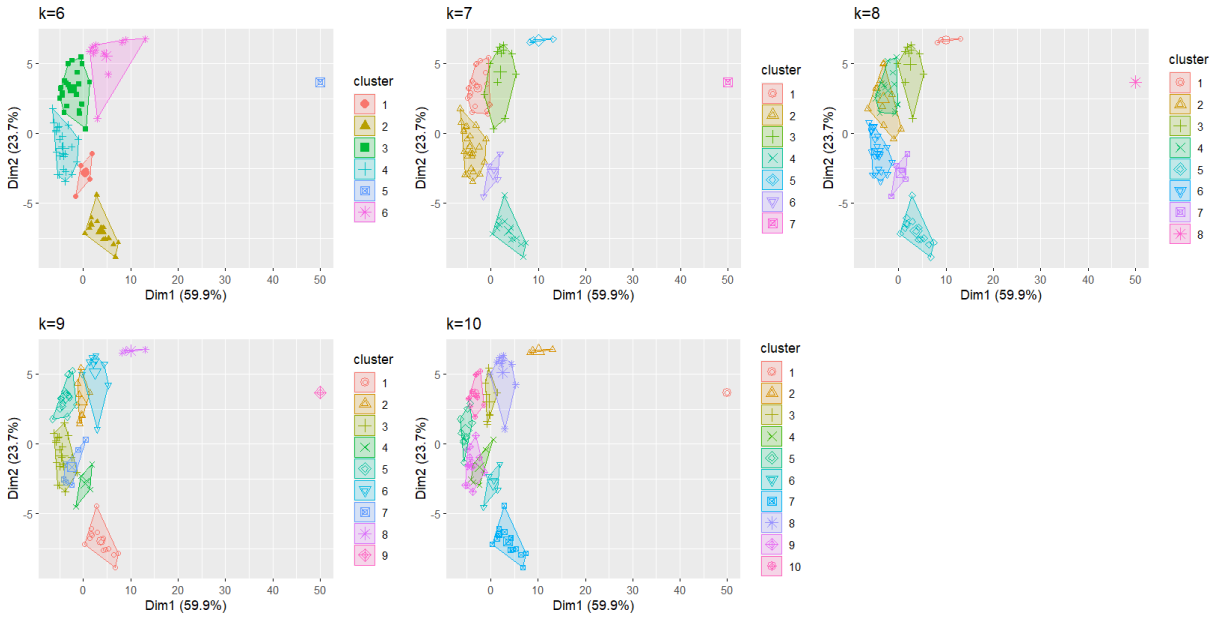
Tablo 1. Kriterler

SN	Kriter	SN	Kriter
1	Nüfus	12	İmalat sanayi hacmi (bin TL)
2	Nüfus yoğunluğu	13	İnşaat hacmi (bin TL)
3	Net iç göç	14	Tarım, ormancılık ve balıkçılık hacmi (bin TL)
4	Net dış göç	15	Yoksulluk sınırı
5	Yıllık nüfus artış hızı	16	Kişi başına düşen tasarruf mevduatı
6	Kişi Başına Gayrisafi Yurt İçi Hasıla (GSYİH)	17	Temel ihtiyaçlarını karşılayamadığını beyan eden hanelerin oranı (%)
7	İşgücü (bin kişi)	18	Orta ve üstü gelir grubundaki hanelerin oranı
8	İstihdam	19	PM10 istasyon değerleri ortalaması (µg/m³)
9	İşsiz nüfus	20	Ortalama günlük kazanç (TK)
10	İthalat (bin TL)	21	Yoksul sayısı (bin kişi)
11	Sanayi hacmi (bin TL)	22	Yoksulluk oranı (%)

Veri ön işleme adımlarında veri setinin tanımlayıcı istatistikleri elde edilmiş, "nüfus yoğunluğu" ve "imalat sanayi hacmi" diğer kriterlerle yüksek korelasyondan dolayı veri setinden çıkarılmış ve çalışma kalan 20 kriter ile devam ettirilmiştir. Sonrasında veriler normalize edilmiştir.

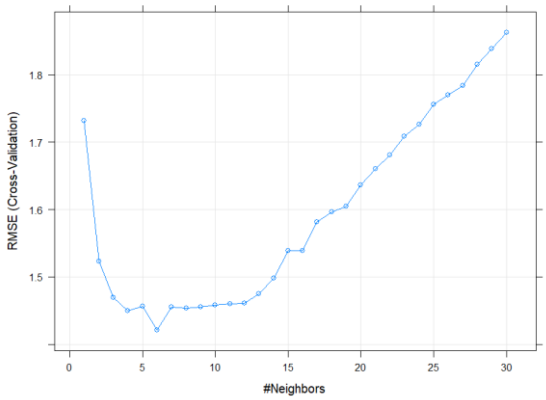
K-ortalamalar yönteminden elde edilen sonuçlar Şekil 2'de gösterilmiştir.





Şekil 2. K-ortalamalar kümeleme sonuçları

Çalışmada, K-ortalamalar yöntemiyle sınıf etiketleri belirlendikten sonra kümeleme başarısı sınıflandırma yöntemleriyle değerlendirilmiştir. Doğru yapılmış bir kümeleme, sınıflandırma yöntemlerinin de başarısını arttıracaktır. KNN yöntemi uygulanırken tüm hesaplamalarda en yakın komşu sayısı için çapraz doğrulama yapılmıştır. Çarpraz doğrulama, yapılan bir istatistiksel analizin bağımsız bir veri setinde nasıl bir sonuç elde edeceğini sınayan bir model doğrulama tekniğidir. Örnek olarak 4 küme için yapılan çapraz doğrulama Şekil 3'te gösterilmiştir. Şekil 3'e göre seçilmesi gereken komşu sayısı 7'dir.



Şekil 3. KNN için çapraz doğrulama (cross-validation)

Çapraz doğrulamalara göre KNN yönteminden elde edilen sonuçlar Tablo 2'de gösterilmiştir. Tablo 2'ye göre en uygun sınıf sayısı 4'tür.

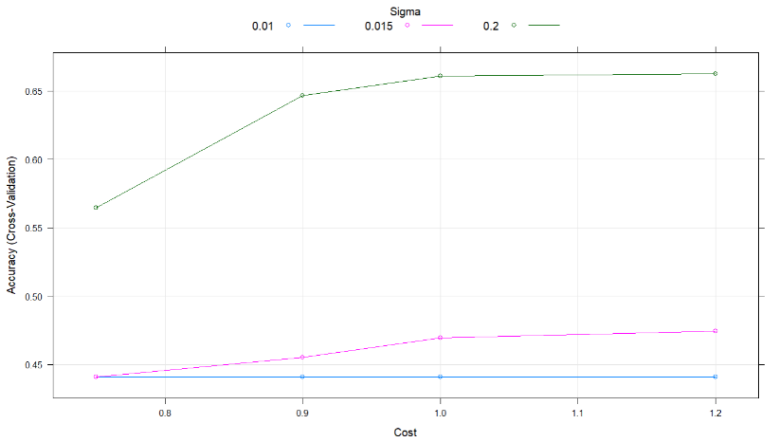
Tablo 2. KNN sonuçları

SN	Küme Sayısı	En Yakın Komşu Sayısı (k)	Sınıf Hatası
1	4	7	0.0714285
2	5	11	0.2666667
3	6	3	0.2857143
4	7	7	0.2142857
5	8	3	0.1333333
6	9	3	0.3571429
7	10	2	0.4482759

Analize göre Türkiye'nin illerinin kümelenmesi Şekil 3'teki gibidir.

Şekil 3. k=4 için kümeleme sonuçları

SVM yönteminde de farklı σ ve C (cost) değerleri için çapraz doğrulama yapılmıştır. Destek vektör sayıları ise model tarafından atanmaktadır. SVM için örnek bir çapraz doğrulama Şekil 4'te gösterilmiştir.



Şekil 4. SVM için çapraz doğrulama (cross-validation)

Çapraz doğrulamalara göre SVM yönteminden elde edilen sonuçlar Tablo 3'te sunulmuştur. Tablo 3'e göre en uygun sınıf sayısı 6'dır.

Tablo 3. SVM sonuçları

SN	Küme Sayısı	Destek Vektör Sayısı	Parametreler	Tahmin Hatası
1	4	52	σ = 0.015, C = 1.2	0.07142857
2	5	65	σ = 0.015, C = 0.75	0.1333333
3	6	64	σ = 0.2, C = 0.9	0
4	7	76	σ = 0.01, C = 5	0.07142857
5	8	66	σ = 0.2, C = 1.2	0.2666667
6	9	66	σ = 0.2, C= 1.2	0.3571429
7	10	68	σ = 0.1, C = 5.1	0.4615385

Analize göre Türkiye'nin illerinin kümelenmesi Şekil 5'teki gibidir.

Şekil 5. k=6 için kümeleme sonuçları

SONUÇ VE ÖNERİLER

Türkiye hem coğrafik ve jeolojik hem de sosyoekonomik özellikleri bakımından çeşitlilik gösteren bir ülkedir. Bu nedenle Türkiye'nin her bölgesinin enerji ihtiyacının eşit olduğunu söylemek doğru olmaz. Bunun yanı sıra Türkiye enerji ihtiyacı bakımından çoğunlukla dışa bağımlı bir ülke olduğundan yenilenebilir enerji politikalarının doğru uygulanması ve yatırımların doğru yapılması çok önemlidir. Türkiye için tek bir yenilenebilir enerji kaynağı önermek yerine bölgesel bazda değerlendirme yapmak önerilebilir. Bu nedenle çalışmada, Türkiye'nin illeri enerji ihtiyaçlarına göre sosyoekonomik özellikler çerçevesinde kümelenmiştir. Öncelikle K-ortalamalar yöntemiyle küme sayısı 4, 5, 6, 7, 8, 9 ve 10 olmak üzere iller yirmi sosyoekonomik kritere göre kümelenmiştir. K-ortalamalar yöntemiyle sınıf etiketleri atandıktan sonra hangi kümenin seçilmesi gerektiğinin analizi için makine öğrenmesi yöntemlerinden KNN ve SVM yöntemleri kullanılmıştır. Yöntemlerin sınıflama hataları hesaplanarak en uygun kümelemeler belirlenmiştir. KNN yöntemine göre küme sayısı 4, SVM yöntemine göre küme sayısı 6 olarak tespit edilmiştir. Her iki kümelemede de bekleneceği üzere İstanbul diğer illerden ayrılmış ve en yüksek enerji ihtiyacına sahip il olarak tespit edilmiştir. İlerleyen çalışmalarda kriterler arasına illerin konumları ve yenilenebilir enerjiye dair kriterler de eklenerek çalışma geliştirilebilir.

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TÜRKİYE İLLERİNİN YENİLENEBİLİR ENERJİ POTANSİYELLERİNE GÖRE BULANIK KÜMELENMESİ

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ÖZET

Ülkelerin ekonomik ve sosyal kalkınmaları için gerekli en önemli kaynaklardan biri enerjidir. Artan dünya nüfusu, her gün gelişen teknoloji ve hızlı sanayileşme enerji ihtiyacını da büyük oranda arttırmıştır. Günlük hayat için de vazgeçilmez bir unsur olan enerji diğer tükenebilir kaynaklar gibi hızla azaldığından yenilenebilir enerji kaynaklarına (YEK) olan ihtiyaç da artmaktadır. Türkiye gibi coğrafi özellikleri ve iklim koşulları bölgeden bölgeye değişen bir ülke için tek bir YEK önermek doğru olmayabilir. Bunun yerine bölge özelinde YEK potansiyeli ve sosyoekonomik özelliklere dayalı analizler daha etkili olabilir. Bu çalışmada, Türkiye'nin illeri sosyoekonomik özellikleri ve konumları da dikkate alınarak YEK potansiyellerine göre kümelenmiştir. Bunun için; yüzölçüm, nüfus, kişi başına gayri safi milli hasıla (GSYİH), alınan göç, verilen göç, istihdam ve sanayi hacmi gibi yirmi bir sosyoekonomik kriter belirlemiştir. YEK potansiyeli için ise ortalama sıcaklık, ortalama rüzgâr hızı, toplam yağış miktarı, toplam ortalama debi, sulama alanı, orman serveti, tarımsal alanlar gibi yirmi beş kriter ele alınmıştır. Son olarak illerin konumları probleme enlem, boylam, kuzeydoğu sınırı enlem ve boylam, güneybatı sınırı enlem ve boylam olarak dâhil edilmiştir. Ardından tüm kriterler bir arada değerlendirilerek iller bulanık C-ortalamalar (Fuzzy C-means - FCM) algoritmasıyla küme sayısı 4, 5, 6, 7, 8, 9 ve 10 olmak üzere kümelenmiştir. İkinci olarak, veri setindeki kriterler "sosyoekonomik", "konum" ve "YEK potansiyeli" olarak üçe ayrılarak ağırlıklandırılmış ve bulanık C-ortalamalar algoritması yeniden uygulanmıştır. Böylelikle farklı ağırlıkların sonuçlara etkisi analiz edilmiştir. Son olarak kümeleme başarısının tespit edilmesi için sınıflama algoritmalarından Rassal Orman (Random Forest - RF) kullanılmış ve her küme için doğruluk değeri bulunmuştur.

Keywords: Yenilenebilir enerji kaynağı (YEK), bulanık kümeleme, bulanık C-ortalamalar (FCM), rassal orman (RF).

FUZZY CLUSTERING OF TÜRKİYE'S PROVINCES ACCORDING TO RENEWABLE ENERGY POTENTIALS

ABSTRACT

One of the most crucial resources for the economic and social development of countries is energy. The increasing global population, evolving technology on a daily basis, and rapid industrialization have significantly escalated the demand for energy. Energy, an indispensable element for daily life, is diminishing rapidly, similar to other finite resources, necessitating an increased reliance on renewable energy sources (RES). Proposing a single type of RES for a country with diverse geographical and climatic conditions like Turkey may not be accurate. Instead, region-specific analyses based on RES potential and socioeconomic characteristics might prove more effective. In this study, Turkish provinces were clustered based on their RES potentials, considering both their socioeconomic features and locations. To achieve this, twenty-one

socioeconomic criteria such as land area, population, per capita gross national income (GNI), immigration, emigration, employment, and industrial capacity were determined. Additionally, twenty-five criteria, including average temperature, average wind speed, total precipitation, total average flow rate, irrigated area, forest wealth, and agricultural areas, were considered for RES potential. Finally, the geographical locations of provinces were incorporated into the problem, including latitude, longitude, northeast boundary latitude and longitude, and southwest boundary latitude and longitude. Subsequently, all criteria were collectively evaluated, and the provinces were clustered using the Fuzzy C-means (FCM) algorithm with cluster numbers of 4, 5, 6, 7, 8, 9, and 10. Secondly, the criteria in the dataset were divided into three categories: "socioeconomic," "location," and "RES potential," and were weighted accordingly. The fuzzy C-means algorithm was then reapplied. This allowed the analysis of the impact of different weights on the results. Finally, for the determination of clustering success, the Random Forest (RF) classification algorithm was employed, and accuracy values were obtained for each cluster.

Keywords: Renewable energy sources (RES), fuzzy clustering, fuzzy C-means (FCM), random forest (RF).

GİRİŞ

Endüstri Devrimi ile başlayan enerji ihtiyacı artışı, teknolojik gelişmeler, sanayileşme ve artan Dünya nüfusu ile birlikte hızlanarak devam etmiştir. Enerji, günlük hayat için vazgeçilmez olmasının yanında ekonomik ve sosyal kalkınma için en önemli kaynaklardan biri olup bir ülkenin kendine yetebilmesi ve dışa bağımlı olmaması için vazgeçilmez bir unsurdur. Dünyada enerji tüketimi bazı bölgelerde daha az bazı bölgelerde daha çok olmak üzere genel olarak artış eğilimindedir. Ayrıca bu ihtiyacın çok büyük bir kısmı kömür, petrol ve doğal gaz gibi fosil yakıtlardan elde edilmektedir. Fosil yakıtların çevreye ve insan sağlığına olan olumsuz etkileri bilindiğinden günümüzde alternatif ve temiz enerji kaynağı arayışı tüm Dünya ülkeleri için en önemli konulardan biri haline gelmiştir.

Türkiye, artış gösteren genç nüfusu, sanayi yatırımları ve büyümekte olan ekonomisi ile enerji ihtiyacı yüksek bir ülkedir. Enerji ihtiyacının büyük çoğunluğunu dışardan sağlayan ülkemizin bu konuda dışa bağımlı olduğu söylenebilir. Fosil yakıt fiyatlarının Dünya çapında artışı ve ülkemizdeki döviz kuru göz önüne alındığında ülkemiz için alternatif enerji kaynaklarının ne kadar önemli olduğu açıktır. Türkiye, linyit dışındaki fosil yakıt türlerinden zengin değildir. Ancak başta hidrolik, rüzgâr, güneş, biyokütle ve jeotermal enerjileri olmak üzere yenilenebilir enerji kaynakları (YEK) potansiyeli yönünden fosil kaynaklara göre daha avantajlı durumdadır (Yılmaz M. , 2012). Ülkemizin dışa bağımlılığını azaltmak ve çevre ile sağlığa olan etkileri göz önüne alındığında YEK için yapılacak yatırımlar oldukça önemlidir.

Türkiye jeolojik özellikleri bakımından çeşitlilik gösteren, üç farklı iklime ve farklı bitki örtülerine sahip bir ülkedir. Bunun yanı sıra bölgelere göre sosyoekonomik bakımdan da büyük farklılıklar göstermektedir. Bu nedenle ülkemiz için tek bir YEK önermek doğru olmayabilir. Bunun yerine yatırım kararları bölgesel bazda incelemeler ile verilmelidir. Bu çalışmada, Türkiye'nin illeri sosyoekonomik özellikleri ve konumları da dikkate alınarak YEK potansiyellerine göre bulanık C-ortalamalar (Fuzzy C-means - FCM) algoritmasıyla kümelenmiştir. Sosyoekonomik özellikler için 21, konum özellikleri için 4 ve YEK potansiyeli için 25 kriter dikkate alınarak kriterler oldukça geniş tutulmuştur. Öncelikle tüm kriterler tek başlık altında ve eşit önemde kabul edilmiş ve küme sayısı 4, 5, 6, 7, 8 ve 9 olmak üzere kümeleme yapılmıştır. Ardından veri setindeki kriterler "sosyoekonomik", "konum" ve "YEK potansiyeli" olarak üçe ayrılarak ağırlıklandırılmış ve bulanık C-ortalamalar algoritması küme sayısı 4, 5, 6, 7, 8 ve 9 olmak üzere yeniden uygulanmıştır. Böylelikle farklı ağırlıkların sonuçlara etkisi analiz edilmiştir. Elde edilen kümelerden hangisinin seçilmesi gerektiği ise sınıflama algoritmalarından Rassal Orman (Random Forest - RF) ile analiz edilmiştir. Kümeleme sonucu elde edilen sınıflar veri etiketi olarak kullanılarak RF algoritması uygulanmış ve her küme için doğruluk değerleri hesaplanmıştır.

YÖNTEM

Çalışmada, öncelikle Türkiye'nin illeri Bulanık C-Means (FCM) algoritması ile kümelenmiş ve sınıf etiketleri veri kümesine dâhil edilmiştir. Ardından, problem bir sınıflama problemi gibi ele alınarak Rassal Orman (Random Forest- RF) algoritması kullanılmış ve doğruluk değerleri hesaplanarak kümeleme başarısı analiz edilmiştir.

Bulanık C-Means (FCM) Algoritması

Kümeleme, bir veri setinde incelenen birimleri benzerliklerine göre belirli gruplar altında toplayarak, birimlerin ortak özelliklerini tespit etmek ve kümeler ile ilgili genel tanımlamalar yapabilmek için kullanılan bir yöntemdir. Kümelemede amaç küme için benzerliği maksimum, kümeler arası benzerliği ise minimum yapmaktır. Bulanık kümeleme ise bulanık mantık kuramının kümelemede kullanılmasıdır. Yöntemde, bir birim farklı kümelere 0 ile 1 arasındaki farklı üyelik değerleri ile ait olabilir. Klasik kümelemede olduğu gibi bulanık kümelemede de uzaklıklar uzaklık metrikleriyle hesaplanır (Zorlutuna & Erilli, 2018). Bu çalışmada literatürde de en sık kullanılan uzaklık metriği olan Öklid mesafesi kullanılmıştır.

Bulanık C-Means (FCM) algoritması bulanık kümeleme yöntemleri arasında en çok kullanılanlardan biridir. Çoğu bulanık kümeleme algoritması gibi amaç fonksiyonu tabanlı olup amaç fonksiyonun belirlenen minimum ilerleme değerine yakınsamasıyla algoritma durdurulur. Bu sırada, en küçük kareler yönteminin genellemesi olan amaç fonksiyonu minimize edilir. *U* üyelik matrisinin rasgele atanmasıyla algoritma başlatılır ve merkez vektörleri hesaplanır. Hesaplanan küme merkezlerine göre *U* matrisi yeniden hesaplanır. Eski *U* matrisi ile yeni *U* matrisi arasındaki fark ε'dan küçük olana kadar işlemler devam eder (Güleryüz E. , 2022). Yöntem, Denklem 1, 2 ve 3 ile formülize edilmiştir (Bezdek, 1981):

$$J_m = \sum_{i=1}^{N}\sum_{j=1}^{C} u_{ij}^{m} \left\| x_i - c_j \right\|^2 \tag{1}$$

$$c_j = \frac{\sum_{i=1}^{N} u_{ij}^{m} x_i}{\sum_{i=1}^{N} u_{ij}^{m}} \tag{2}$$

$$u_{ij} = \frac{1}{\sum_{k=1}^{C} \left(\frac{\left\| x_i - c_i \right\|}{\left\| x_i - c_k \right\|}\right)^{\frac{2}{(m-1)}}} \tag{3}$$

Rassal Orman (Random Forest- RF)

Sınıflandırma, daha karmaşık bilgileri keşfetmek amacıyla, verileri önceden etiketlenmiş gruplara ayırmak için kullanılan bir makine öğrenmesi yöntemidir. Karar ağaçları (Decision Tree), güçlü öğrenme yetenekleri ile en sık kullanılan sınıflandırma algoritmalarından biridir. Ancak karar ağaçlarının güçlü öğrenme yetenekleri aşırı uyum (overfitting) dezavantajını beraberinde getirir. Rassal Orman (Random Forest- RF) yöntemi de karar ağaçlarına dayalı bir sınıflandırma yöntemidir. Breiman (2001) tarafından literatüre kazandırılan algoritma, yeniden örnekleme yoluyla rastgele örnekler seçer, bu rastgele örneklere dayanarak birden fazla karar ağacı oluşturur, karar ağaçlarının tahminlerini birleştirir ve oylama yoluyla son tahmin sonucunu yüksek bir tahmin doğruluğu ile elde eder. Yöntemde ağaç serbest bir şekilde büyüdüğü için budanmaya ihtiyaç duymaz, bu nedenle "aşırı uyum (over fitting)" dezavantajından kaçınılmış olur (Güleryüz E. , 2022). RF modelinin oluşturulması için karar ağaçlarının sayısı (*ntree*) ve bölünmüş düğümlerin sayısı (*mtry*) olmak üzere iki parametreye ihtiyaç duyulur (Andrade, Faria, Silva, Chakraborty, & Curi, 2020).

BULGULAR

Çalışmada, Türkiye'nin illeri sosyoekonomik özellikleri ve konumlarına göre YEK potansiyelleri kapsamında FCM algoritmasıyla kümelenmiştir. Bunun için öncelikle kriterler belirlenmiştir. Sosyoekonomik özellikler için 21, konum özellikleri için 6 ve YEK potansiyeli için 25 kriter ele alınmıştır. Sosyoekonomik kriterler Tablo 1'de, konum kriterleri Tablo 2'de ve YEK potansiyeli kriterleri Tablo 3'te gösterilmiştir.

Tablo 1. Sosyoekonomik Kriterler

No	Sosyoekonomik Kriterler	No	Sosyoekonomik Kriterler
1	Yüzölçüm	12	İşsiz nüfus-2021
2	Nüfus- 2022	13	İşgücü (bin kişi)-2021
3	Yıllık nüfus artış hızı (‰) -2021	14	İstihdam (bin kişi) -2021
4	Nüfus yoğunluğu-2022	15	Yoksulluk sınırı (TL) -2021
5	Alınan İç Göç-2021	16	Yoksul sayısı (bin kişi) - 2021
6	Verilen İç Göç-2021	17	Sanayi hacmi - (bin TL) -2021
7	Alınan Dış Göç-2021	18	İnşaat hacmi (bin TL) - 2021
8	Verilen Dış Göç-2021	19	Tarım, ormancılık ve balıkçılık hacmi (bin TL-2021)
9	Kişi başına GSYİH-2021	20	Faturalanan elektrik tüketimi (MWh) – 2020
10	Toplam ihracat (bin $)-2022	21	PM10 istasyon değerleri ortalaması
11	Toplam ithalat (bin $)- 2022		

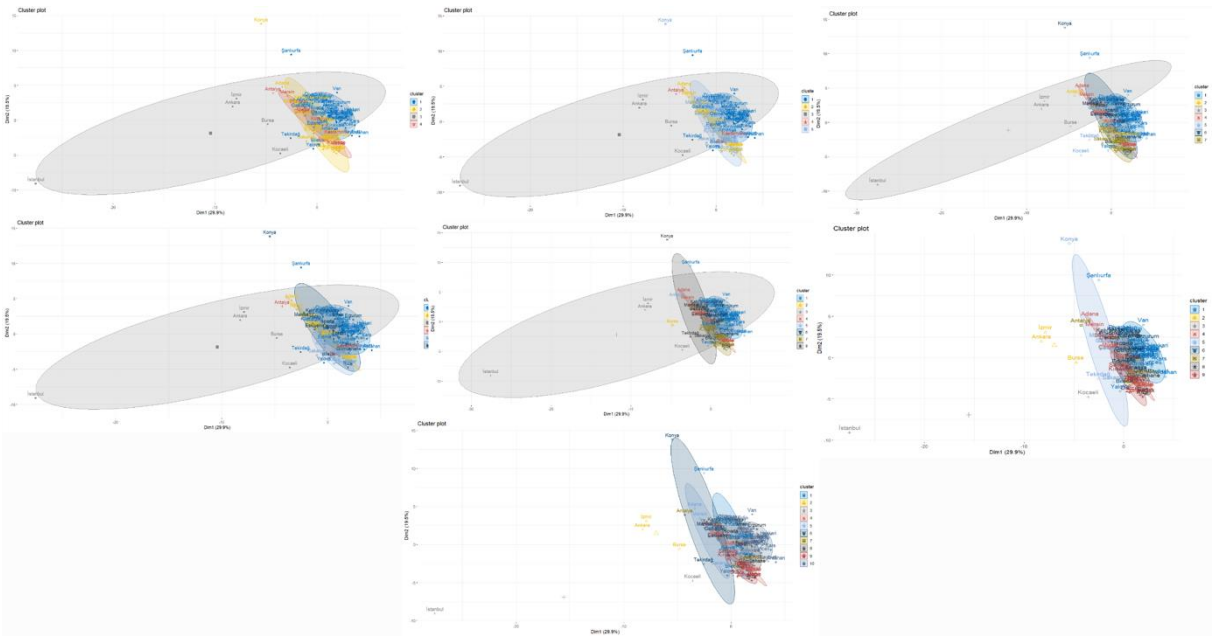
Tablo 2. Konum Kriterleri

No	Konum Kriterleri
1	Enlem
2	Boylam
3	Kuzeydoğu sınırı enlem
4	Kuzeydoğu sınırı boylam
5	Güneybatı sınırı enlem
6	Güneybatı sınırı boylam

Tablo 3. YEK Potansiyeli Kriterleri

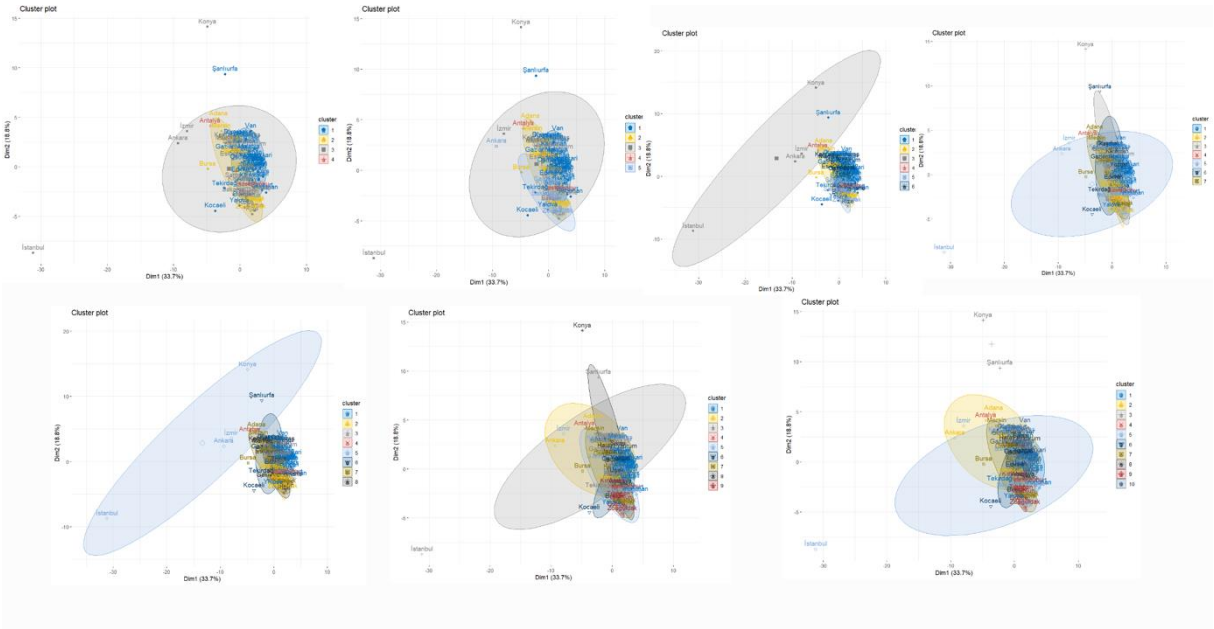
No	YEK Potansiyeli Kriterleri	No	YEK Potansiyeli Kriterleri
1	Radyasyon değeri (KWh/m^2-yıl)	14	Tarımsal alanlar (ha) - 2018
2	Ortalama sıcaklık (°C)	15	Toplam işlenen tarım alanı (ha) - 2021
3	Ortalama en yüksek sıcaklık (°C)	16	Yapay alanlar (ha) - 2018
4	Ortalama en düşük sıcaklık (°C)	17	Orman ve yarı doğal alanlar (ha) - 2018
5	Ortalama güneşlenme süresi (saat)	18	Sulak alanlar (ha) -2018
6	Ortalama rüzgar hızı (m/s)	19	Su kütleleri (ha) - 2018
7	Ortalama rüzgar gücü yoğunluğu (W/m^2)	20	Sulama alanı (ha) - 2018
8	Ortalama rüzgar kapasite faktörü (%)	21	Orman serveti (m^3) - 2021
9	Ortalama yağışlı gün sayısı	22	Toplam bitki besin maddesi tüketimi - 2021
10	Toplam yağış miktarı	23	Bitkisel üretim değeri (bin TL) - 2021
11	Toplam ort debi (m^3/sn) - 2021	24	Canlı hayvanlar değeri (bin TL) - 2021
12	Rakım	25	Tahıllar ve diğer bitkisel ürünlerin üretim miktarı (ton) - 2021
13	Yeraltı suyu (hm^3/yıl) - 2021		

Tüm kriterler bir arada (hiyerarşik olmadan) değerlendirildiğinde FCM algoritmasıyla elde edilen kümeler Şekil 1'de gösterilmiştir.



Şekil 1. FCM algoritması kümeleme sonuçları (ağırlıksız)

İkinci olarak, veri seti "sosyoekonomik", "konum", "yek potansiyeli" ana kriterler olmak üzere ayrılmış ve ana kriterler ağırlıklandırılmıştır. Burada konum, yek potansiyeli ve sosyoekonomik kriterlerin ağırlıkları uzman görüşü ile sırasıyla 0.6017, 0.3087 ve 0.0896 olarak belirlenmiştir. Ağırlıklı veri setinin FCM algoritmasıyla kümelenmesi ile elde edilen sonuçlar Şekil 2'de gösterilmiştir.



Şekil 2. FCM algoritması kümeleme sonuçları (ağırlıklı)

Çalışmada, FCM algoritmasıyla kümeleme yapılıp sınıf etiketleri (Küme 1, Küme 2 vb.) belirlendikten sonra kümeleme başarısının tespit edilmesi ve nihai kümelere karar verilebilmesi için tüm kümelemeler Rassal Orman (RF) algoritmasıyla sınıflandırılmış ve doğruluk değerleri bulunmuştur. Doğru yapılmış bir kümeleme, sınıflandırma yöntemlerinin başarısını da arttıracaktır. RF yöntemi uygulanırken tüm hesaplamalarda ağaç sayısı sabit tutulmuş ve her daldaki değişken sayısına göre çapraz doğrulama yapılmıştır. Çarpraz doğrulama, yapılan bir istatistiksel analizin bağımsız bir veri setinde nasıl bir sonuç elde edeceğini sınayan bir model

doğrulama tekniğidir. Kümeleme başarısı doğruluk değerleri ile sınanmıştır. Doğruluk değerlerinin hesaplanmasında ise Karmaşıklık Matrisi (Confusion Matrix) dikkate alınmıştır. Örnek bir Karmaşıklık Matrisi Şekil 3'te verilmiştir.

```
Confusion matrix:
  1  2 3  4 class.error
1 7  2 1  2  0.41666667
2 1 16 0  1  0.11111111
3 0  1 8  3  0.33333333
4 0  1 0 16  0.05882353
```

Şekil 3. Karmaşıklık Matrisi (Confusion Matrix)

Çapraz doğrulamalara göre ağırlıklı olmayan veri setinden elde edilen sonuçlar Tablo 4'te gösterilmiştir. Tablo 4'e göre en uygun sınıf sayısı 4 ya da 5'tir.

Tablo 4. RF Sonuçları (Ağırlıklı olmayan veri seti)

Küme Sayısı	Ağaç Sayısı	Her Daldaki Değişken Sayısı	Doğruluk
4	500	10	76.27%
5	500	10	76.27%
6	500	10	67.80%
7	500	10	70.00%
8	500	8	51.67%
9	500	9	59.68%
10	500	9	54.10%

Analize göre Türkiye'nin illerinin kümelenmesi Şekil 4 ve Şekil 5'teki gibidir.

Şekil 4. k=4 için kümeleme sonuçları

Şekil 5. k=5 için kümeleme sonuçları

Ağırlıklı veri setinden elde edilen sonuçlar ise Tablo 5'te gösterilmiştir. Tablo 5'e göre en uygun sınıf sayısı 5'tir.

Tablo 5. RF Sonuçları (Ağırlıklı veri seti)

Küme Sayısı	Ağaç Sayısı	Her Daldaki Değişken Sayısı	Doğruluk
4	500	10	72.41%
5	500	10	79.31%
6	500	10	70.69%
7	500	9	63.33%
8	500	10	53.33%
9	500	10	52.46%
10	500	10	45.16%

Analize göre Türkiye'nin illerinin kümelenmesi Şekil 6'daki gibidir.

Şekil 6. k=5 için kümeleme sonuçları

SONUÇ VE ÖNERİLER

Türkiye hem coğrafik ve jeolojik hem de sosyoekonomik özellikleri bakımından çeşitlilik gösteren bir ülkedir. Bu nedenle ülkemize uygun tek bir YEK olduğunu söylemek doğru olmaz. Ayrıca ülkemizin her bölgesinin enerji ihtiyacı eşit değildir. Bu bağlamda yenilenebilir enerji politikalarının doğru uygulanması ve yatırımların doğru yapılması için bölgesel bazda çalışmalar yapmak gerekir. Bu çalışmada, bölgelere özel YEK'in belirlenmesi için ilk adım olarak Türkiye'nin illeri sosyoekonomik özellikleri ve konumlarına göre YEK potansiyellerine göre kümelenmiştir. Bunun için; yüzölçüm, nüfus, kişi başına gayri safi milli hasıla (GSYİH), alınan göç, verilen göç, istihdam ve sanayi hacmi gibi yirmi bir sosyoekonomik kriter belirlemiştir. YEK potansiyeli için ortalama sıcaklık, ortalama rüzgâr hızı, toplam yağış miktarı, toplam ortalama debi, sulama alanı, orman serveti, tarımsal alanlar gibi yirmi beş kriter ele alınmıştır. Son olarak illerin konumları probleme enlem, boylam, kuzeydoğu sınırı enlem ve boylam, güneybatı sınırı enlem ve boylam olarak dâhil edilmiştir. Böylece kriterler oldukça geniş tutulmuştur. Kümeleme için bir bulanık kümeleme algoritması olan FCM kullanılmış ve algoritma küme sayısı 4, 5, 6, 7, 8 ve 9 olarak çalıştırılmıştır. Kriterler önce hiyerarşik olmadan değerlendirilmiş, ardından "sosyoekonomik", "konum", "yek potansiyeli" olmak üzere ayrılarak ağırlıklandırılmıştır. Tüm kümelemelerin başarısı sınıflama algoritmalarından RF ile doğruluk değerleri hesaplanarak sınanmıştır. Ağırlıklandırmanın kümeleme başarısını arttırdığı ve en uygun küme sayısının 4 ya da 5 olduğu tespit edilmiştir. İlerleyen çalışmalarda kümelere özel uygun YEK'in belirlenmesi için bir Çok Kriterli Karar Verme (ÇKKV) yöntemi kullanılabilir.

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ONE OF THE SECOND GENERATION ENERGY SOURCES FOR AGRICULTURAL ENERGY: INDUSTRIAL HEMP

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ABSTRACT

Energy; It is a necessary and unique resource for sustaining daily life and performing all vital, biochemical activities. The demand for renewable energy sources continues to increase day by day, especially due to the negative effects of fossil energy resources on the environment.

While the production and use of a wide variety of renewable energy sources in the world has now become a discipline, the constant increase in energy needs has led humanity to new and alternative renewable energy sources and continues to do so. On our planet, in addition to the natural energy resources such as sun, wind and water, almost all kinds of plant biomass-based alternative renewable biofuel (agricultural energy) resources, especially plant and food residues, are produced and used, and research is carried out on their efficiency and diversity continues.

Instead of first generation plants, which are important for their consumption as food and therefore disadvantageous in their preferability in energy production, second and even third generation agricultural energy production and use, in which algae (seaweed) are used as raw materials, continues to increase day by day in the world.

Although second generation biofuel sources, which are advantageous in terms of agricultural energy sources, vary, we can contribute to our country's **"Energy Supply Security"** by developing new production processes that will both increase this diversity and produce higher energy from these sources.

Industrial Hemp is a plant with a low water mark, which is currently allowed to be produced in 20 provinces in our country, has a very high potential to transform all biomass into high value-added products, has many benefits for the agricultural cultivation areas and the region where it is located, and does not require the use of pesticides in its cultivation; It is a biomass that has the potential to become a second generation raw material in agricultural energy production.

It is thought that there is more studies out at all levels on the use of hemp biomass in energy production within Yozgat Bozok University (YOBÜ), specialized in the field of "Industrial Hemp" focusing on regional development, are more meaningful, necessary and important. It seems possible to produce hemp seed-based biodiesel, cellulosic bioethanol production and even to manufacture "Super Capacitors" (New Generation Battery) by obtaining activated carbon from hemp.

In this paper, the studies carried out so far on renewable energy resources, especially agricultural energy resources, and in the case of "Industrial Hemp"; It is aimed to increase the diversity of second generation biofuels, which is very important, and to compile research on the production of more efficient energy raw materials and to put forward different suggestions.

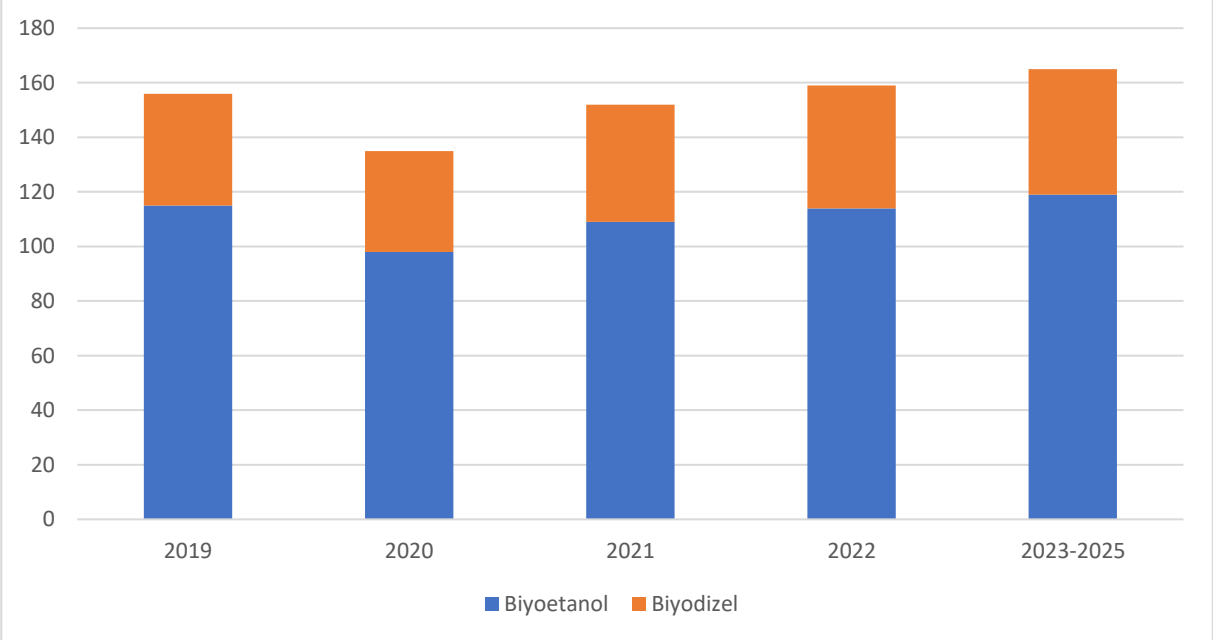
Keywords: Biofuel, agricultural energy, ındustrial hemp, renewable energy, sustainable energy

INTRODUCTION

Energy is considered to be one of the most important resources of our age. Safe, sustainable, environmental energy resources enable the country's socio-economic development. With the increasing impact of greenhouse gas emissions on the climate, increasing energy prices and increasing dependence on fossil fuels, countries need to focus on renewable energy sources, including bioenergy (Solomon et al., 2007). There has been a steady increase in the consumption of fossil fuels, especially oil, from the late nineteenth century to the present. Energy resources have become more expensive and difficult to access, necessitating the search for alternative, domestic, renewable energy sources (Sosa et al., 2019).

Bioenergy is a resource obtained from biomass that has emerged as an alternative to fossil fuels and has a high potential. Bioenergy products such as biogas, biodiesel, bioethanol, biobutanol and biohydrogen can be produced from biomass (Ozturk et al., 2017). Energy production from biomass also offers some benefits over fossil fuels: it can be produced in large quantities on a regular basis, it is mostly a waste product and is therefore inexpensive. At the same time, biomass is a sustainable carbon neutral resource (Pols & Spahn, 2014). Each of these features gives biomass a significant potential. World biofuel production is increasing day by day (Table 1). The demand for biomass and biofuels produced from biomass is expected to triple by 2035 (Matzenberger et al., 2015).

Table 1: World biofuel production (IEA, 2019)



Raw material resources that can be used for biofuel production are divided into three groups. First generation biofuels are obtained from sugar cane, corn, wheat, animal fat and vegetable oil sources using traditional technologies. There are environmental and economic concerns regarding 1st generation resources. Since these raw materials are also used as food, it has been reported that they are not sustainable in terms of large-scale bioenergy production as it can seriously harm the food supply (Nair et al., 2017).

Second generation biofuels have begun to be produced in response to increasing demands. Second generation biofuels (waste raw materials) are produced using raw material resources that are not used for food as in the first generation, but are food residues. According to studies, greenhouse gas emissions of biofuels produced from second-generation sources are less than first-generation biofuels. In third generation biofuels, algae are used as a biomass source. It involves the processing of carbohydrates resulting from the fermentation of algae.

Since the biomass obtained from forestry production is low and its production takes a long time, it is likely that short-term resources will play an important role in the future bioenergy mix (CliftonBrown et al., 2007). One of the most promising sources of raw materials for energy production are perennial plants (Bilandžija et al., 2018). A promising lignocellulosic feedstock for bioethanol production is hemp (*Cannabis sativa* L.)

biomass (Hoşgün et al., 2017). Many properties of hemp biomass make it a preferable source of raw materials. These; The hemp plant is extremely durable, adapts perfectly to different climatic conditions, grows in almost every soil, is not susceptible to various pests, and contains high cellulose in hemp biomass (Burczyk et al., 2008). Hemp is promising for biofuel production because it contains more cellulose than other lignocellulosic biomass (Yoo et al., 2017). The content of carbohydrate fractions, including cellulose and hemicellulose, is crucial for the production of fermentable sugar contents. Hemp plants contain high amounts of cellulose (78%) and low amounts of lignin (13%) (Zhao et al., 2020). Fibrous hemp could be a good fuel in the future. A crop called industrial hemp is a biomass source with certain potential.

HEMP BIOMASS

Cannabis plant (*Cannabis sativa* L.) is an annual herbaceous plant belonging to the Cannabaceae family. Industrial hemp plants are generally cultivated to obtain fiber from their stems. Hemp biomass has many properties that make it an excellent source for bioenergy production. Among these features, it is resistant to microbes and its biomass yield is quite high (Shi & Cai, 2009). Hemp produces a large amount of biomass due to its high growth rate. It completes its growth process in approximately 70-140 days. Because it is resistant to the outdoor environment, it can be grown in various climatic conditions. Hemp production is considered an environmentally friendly process (Montford & Small, 1999). An important advantage of hemp compared to other biomass is the size of the biomass obtained. Hemp plants use less water than many other biomass crops (Ranalli & Venturi, 2004). Another issue that affects the cultivation of cannabis plants is temperature. The optimal temperature for hemp growth varies between 10–20 °C, but hemp plants also grow outside this temperature range (Fortenbery & Bennet, 2004). Although diseases are rare in the cannabis plant due to the plant's ability to protect itself from pests, the damage caused by insects to the plant is negligible. Due to these properties of hemp, a minimum amount of biocide is used during its cultivation. Since the cannabis plant is very rich in leaves, the plant makes itself more dominant against other weeds. During the harvest season, hemp leaves, which act as fertilizer to improve soil quality, are reduced (Poisa & Adamovics, 2010). In conclusion, due to the advantages of the hemp plant compared to other biomass, its impact on the environment is quite low compared to other biomass grown for biofuel production, making it a very good source.

When the morphology of the hemp stalk is examined, it is seen that it consists of several layers. Hemp stalk consists of phloem fiber and xylem fibers. Bast fiber, that is, phloem layers, has high cellulose (78%) and low lignin (13%) content (Shahzad, 2012). The xylem and core layers contain approximately 40% cellulose and 17% lignin (Shin et al., 2009). Hemp biomass has been reported to contain high cellulose compared to miscellaneous biomass (Table 2).

Table 2: Chemical composition of some biomass sources

Biomass	Cellulose (%)	Hemiselüloz (%)	Lignin (%)	Reference
Switchgear	5-20	30-50	10-40	Zabed et al., 2017
Common herbs	25-40	25-50	10-30	Zabed et al., 2017
Municipal solid waste	33–49	9-16	10–14	Zabed et al., 2017
Newspapers	40–55	25-40	18-30	Zabed et al., 2017
Corn cob	42–45	35–39	14–15	Zabed et al., 2017
Corn stalk	38-40	24-26	7–19	Zabed et al., 2017
Sugar cane	42–48	19-25	20–42	Zabed et al., 2017
Rice straw	28–36	23–28	12–14	Zabed et al., 2017
Wheat straw	33–38	26–32	17–19	Zabed et al., 2017
Barley straw	31–45	27–38	14-19	Zabed et al., 2017
Sweet sorghum pulp	34–45	18–27	14–21	Zabed et al., 2017
Oat straw	31–37	27–38	16-19	Zabed et al., 2017
Chavdar strawberries	33–35	27-30	16-19	Zabed et al., 2017
Rice husk	25–35	18–21	26–31	Zabed et al., 2017
Softwood	27-30	35-40	25-30	Zabed et al., 2017
Hardwood	20-25	45-50	20-25	Zabed et al., 2017
Spruce tree	46.7	29	26.2	Parvez et al., 2021
Willow	44.4	31	25.5	Parvez et al., 2021
Canary grass	35.9	29.6	5.0	Parvez et al., 2021
Miscanthus	50	25	12	Parvez et al., 2021
Hemp	70-92	18-22	3-5	Sadrmanesh & Chen, 2019

BIOENERGY PRODUCTION FROM INDUSTRIAL HEMP

The impact of the increase in greenhouse gas emissions on the climate has reached serious levels (Solomon et al., 2007), together with the significant increase in energy prices and the increasing dependence on fossil fuels, prompting countries to consider renewable energy sources, including bioenergy. Fossil fuels may run out within the next half century. For this reason, non-renewable fossil fuels are not a reliable energy source due to their depletion over time and environmental risks. Therefore, green or renewable energy sources should be used. Hemp plant, one of the biomass varieties that can provide sustainable production of bioenergy raw materials, is becoming popular with its advantages. Hemp-based biofuel could help reduce dependence on fossil fuels. Industrial hemp may be a promising source of biomass for the production of biofuel and value-added products. Hemp seed oil has been used as fuel in lamps for centuries. It is possible to obtain many energy sources from hemp biomass (Figure 1).

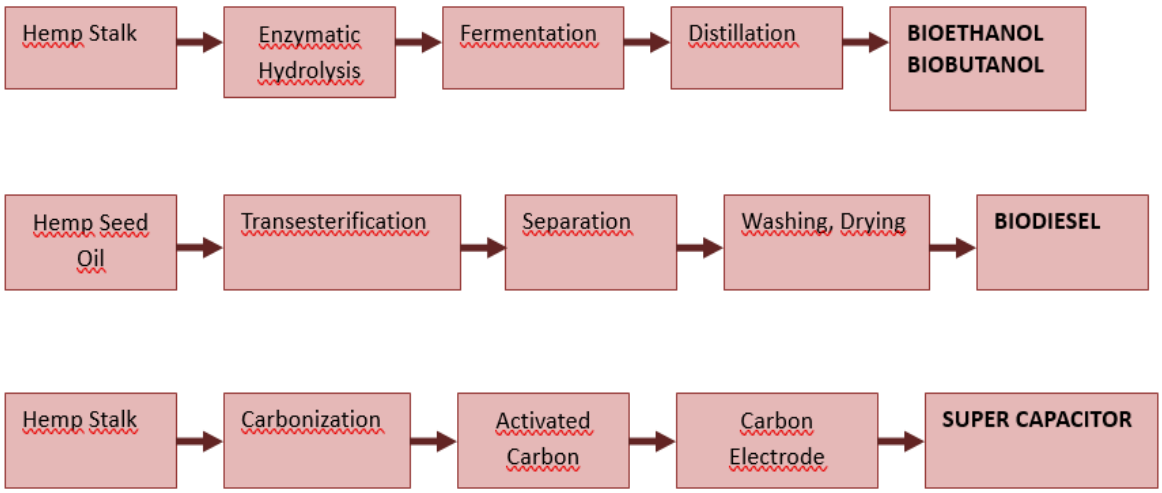


Figure 1: Energy sources obtained from hemp biomass

BIOETHANOL

Bioethanol is an environmentally friendly fuel that replaces fossil fuels, reduces the environmental impact of greenhouse gas emissions and thus creates less air pollution. Although the production of bioethanol is very important, it is an alternative fuel type to gasoline. It is mainly produced from food plants such as sugarcane, corn and rice. However, many studies have reported that bioethanol production from second-generation biomass has a higher energy ratio than ethanol produced from first-generation biomass sources (Wang et al., 2012). Hemp biomass is an alternative, new, cheap and sustainable raw material source to produce bioethanol due to its high amount of cellulose and very low lignin content (Garcia-Jaldon et al., 1998). Its high amount of cellulose and low amount of lignin make hemp an extremely attractive biological source for bioethanol production.

Hemp biomass, like other lignocellulosic biomass, requires pre-treatment techniques to disrupt the biomass structure and reveal the sugar content. Performing these pretreatment techniques causes changes in the structure of hemp biomass and makes cellulose and hemicellulose accessible to enzymes for higher bioethanol production (Himmel et al., 2007). The main purpose of this pre-treatment method is to eliminate the lignin structure, which is cross-linked to the cellulose structure, in order to access the cellulose contained in the biomass (Mooney et al., 1998). Many pre-treatment methods, generally physical, chemical, physicochemical and biological methods, are used to loosen biomass and remove lignin, which hinders bioethanol production, from the biomass structure (Kumar & Sharma, 2017). The purpose of these methods is to facilitate the access of the enzymes to be used in the hydrolysis stage to cellulose and to disrupt the structure of lignocellulose (Dincer, et al., 2021; Hamid et al., 2023).

Chemical methods of pretreatment of lignocellulosic biomass; acid (typically sulfuric or hydrochloric acid), alkaline (sodium hydroxide, calcium carbonate, ammonia), or neutral (ionic liquids, liquid hot water LHW), the organosolv process involves. Physical processes; Mechanical digestion includes microwave, high-energy electron radiation, and pyrolysis. Physico-chemical processes; include steam explosion, SO_2 or ammonia (AFEX) treatment, CO_2 explosion, and electrical catalysis. Biological processes use microorganisms. Generally, fungi are used to decompose lignin (Adıgüzel, 2013; Kumar & Sharma, 2017; Jędrzejczyk et al., 2019; Taymaz & Uslu, 2019). According to Sun & Cheng, (2002), pretreatment methods should increase fermentable sugar formation, should not cause carbohydrate degradation, should prevent the formation of by-products that would cause inhibition in the hydrolysis and fermentation stages, and should be affordable. After the pre-treatment application, the biomass is separated into cellulose and hemicellulose building blocks by hydrolysis. It is seen that a wide variety of microorganisms are used to produce bioethanol for the purpose of fermentation of monosaccharides obtained after the hydrolysis stage of biomass. The most commonly used yeast variety for industrial bioethanol production is *Saccharomyces cerevisiae.* Zhao et al. (2020) investigated four types of hemp biomass subjected to three different pretreatment methods for ethanol production. As a result, effective lignin removal (58.6-75.3%) was achieved with NaOH pretreatment and high ethanol yield was achieved using *Saccharomyces cerevisiae* yeast. They observed conversion of up to 96.7% glucose to

ethanol. Lee et al. (2012) analyzed saccharification and fermentation conditions by immobilizing saccharolytic molds together with *Saccharomyces cerevisiae* to investigate bioethanol production from sweet potatoes reported that the maximum fermentation rate of immobilized yeast cells was 80.23%. Traditional *Saccharomyces cerevisiae* is only capable of fermenting glucose and other 6-carbon sugars, but cannot ferment 5-carbon sugars (Kricka et al., 2015). Considering the high hemicellulose content of hemp biomass, the use of *Saccharomyces cerevisiae* yeast is undoubtedly a waste of resources. Genetically modified microorganisms such as *Saccharomyces cerevisiae*, *Escherichia coli*, *Zymomonas mobilis* or *Klebsiella oxytoca* are used for the fermentation of 6-carbon sugars (Wang et al., 2018). *Wickerhamomyces anomalus* is an organism called non-*Saccharomyces* yeast (Daniel et al., 2010). It has been reported that this organism produces ethanol by fermenting 5-carbon sugars from lignocellulosic biomass and achieves high yield (Bonatto et al., 2020). Thus, high efficiency bioethanol can be obtained by the combined use of yeasts that can ferment 5-carbon and 6-carbon sugars.

BIODIESEL

The high cost of fossil fuel resources and the fact that they will be depleted over time have increased the interest in biodiesel. It has been reported that biodiesel can be used in many automotive engines, such as cars, trucks, and agricultural machinery (Rodionova et al., 2017). It is a renewable fuel source that can be used instead of diesel fuel in automotive engines. Biodiesel is gaining increasing interest worldwide as an alternative to fossil fuels. The production of plant-derived biodiesel is done by using the transesterification method of oils obtained from the seeds of the plant. Biodiesel can be obtained from the seed oils of many biomass. Biodiesel is very popular because it is cheap, sustainable, safe and renewable. These benefits obtained from the use of biodiesel have led to the emergence of many studies on the use of alternative fuels. One of the most suitable sources for biodiesel production is undoubtedly industrial hemp. Hemp is a plant that does not have high costs in growing and has no impact on the environment. After bioethanol, biodiesel is a promising lignocellulosic-derived biofuel. Hemp seeds contain a lot of oil, ranging from 26% to 42% (Kriese et al., 2004). Hemp seeds consist of essential fatty acids such as 52-62% linoleic acid and 12-23% a-linolenic acid (Rehman et al., 2013). Mohammed et al. (2020), in their study, biodiesel produced from hemp (*Cannabis sativa* L.) plant; Euro diesel is blended with mixtures of butanol and diethyl ether. As a result of this study, it was reported that blending improved cold flow properties, kinematic viscosity and density. John et al. (2020), used different methods to scale the quality of biodiesel produced from hemp seeds in their study. As a result, it was reported that the estimated fuel properties were within the standards-compliant range and hemp could be an environmentally friendly fuel compared to conventional diesel. The high oil content of hemp seeds is important for biodiesel production.

BIOBUTANOL

Butanol is an alternative fuel to gasoline due to its high energy content, low volatility, less hygroscopic and less corrosive properties (Ni & Sun, 2009). One of the advantages of biobutanol is that it can be mixed with gasoline at a rate of 85% and does not cause any modifications to vehicles. Biobutanol gasoline blends of up to 16% and 15% are allowed in the United States and Europe, respectively (Wang et al., 2017). In recent years, biobutanol production from lignocellulosic biomass by ABE (acetone, butanol, and ethanol) fermentation method has attracted much attention and its production has also increased. Biobutanol has been successfully obtained from plants from a wide variety of agricultural and forestry wastes such as switchgrass, wheat straw, and rice straw, as well as first-generation sources such as apples, potatoes, grains, corn flour, corn stover, corn fiber, sorghum (Gu et al., 2014; Jurgens et al., 2012; Gottumukkala et al., 2017; Hijosa-Valsero et al., 2017). Butanol and its derivatives are used in paint thinners, hydraulic fluids, perfumes, glass, detergents, de-icing fluids, cosmetics (eye make-up, lip protectors, nail protectors, foundation), extraction liquids used in the production of medicines, alkaloids, antibiotics, hormones and vitamins, and in paper and paper. It is also used in thin layer chromatography and in the food industry (Dürre 2008). After selecting the appropriate biomass for biobutanol production, the pre-treatment method is applied to remove the lignin in the structure. Hydrolysis of lignocellulosic biomass with cellulase requires a mixture of cellulase enzymes at an appropriate ratio. (Ibrahim et al., 2013). At the same time, if the biomass to be used contains high amounts of hemicellulose, xylanase enzymes that hydrolyze hemicellulose can also be used. Enzymatic hydrolysis of lignocellulosic biomass is carried out by hemicellulase and cellulase enzymes (glycoside hydrolases). The saccharification

process of lignocellulosic biomass takes approximately 72 hours. (Linggang et al., 2012). ABE fermentation is a biotechnological process in which fermentable *Clostridium* species convert cellulose, xylose, starch and sugar-containing waste into acetone, butanol and ethanol. In the transformation, they are produced in the ratio of 3-6-1 by mass, respectively. In a study, it was reported that 1.67 tons of ethanol, 4.48 tons of butanol, and 0.63 tons of acetone were produced by using 200,000 tons of solid municipal waste (Ashani et al., 2020). Production of biobutanol and other products by ABE fermentation is carried out by the *Clostridia* species (Tzanetis et al., 2017). Some of these species can be listed as *C. acetobutylicum*, C. *beijerinckii*, *C. madisonii*, *C. saccharoperbutylacetonicum* and *C. saccharoacetobutylicum*. Due to their saccharolytic and amylolytic properties, *Clostridiums*, which are soil bacteria, are in the obligate anaerobe group and carry out fermentation by growing in an inert environment (Visioli et al., 2015). Butanol, ethanol and volatile acids produced during fermentation are analyzed by gas chromatograph. Separation of butanol, ethanol and acetone can be achieved by distillation.

SUPER CAPACITOR

As fossil fuels harm the environment and energy demand increases, there is a need for the development of low-cost energy storage devices. Supercapacitors are energy storage devices. It is one of the promising sources for energy storage devices, thanks to its use in hybrid electric vehicles, electronic devices, distributed sensor networks and its wide application area (Simon & Gogotsi, 2010). Supercapacitors have fast charge-discharge properties, high power density and long lifespan, making them advantageous (Merlet et al., 2012). For a supercapacitor, electric double-layer capacitors (EDLCs) are frequently used. The most commonly used electrode material for EDLCs is activated carbon. Carbon materials are considered an excellent electrode material due to their easy availability, low cost, non-toxicity, large surface area and good conductivity (Wang et al., 2016). So far, activated carbons, carbon nanofibers, carbon nanotubes, carbon airgel, and graphene have been widely investigated for electrode materials (Gunasekaran & Badhulika, 2021). In particular, activated carbons are widely used as electrode materials for supercapacitor production. Biomass-based carbon sources have become popular in the production of supercapacitors. In this direction, waste biomass and lignocellulosic biomass were used as raw materials to produce carbon. Preparation of porous carbon materials from hemp, a lignocellulosic biomass source, has started to attract a lot of attention today. Sun et al. (2016), activated carbons were obtained from raw hemp stalk. As a result of the study, activated carbon was produced from low-dimensional structures with high surface area and large amounts of mesopores. Activated carbons have been used for the electrodes of supercapacitor cells. It has been reported that excellent electrochemical performance was achieved with a high energy density of 19.8 Wh/kg (Sun et al., 2016). Many studies show that hemp biomass can be used as a low-cost and high-efficiency electrode material in supercapacitor production (Xiong et al., 2015; Jiang et al., 2019; Tan et al., 2020).

CONCLUSION

Energy demand is expected to increase over time. Alternative energy sources, especially lignocellulosic biomass resources, need to be evaluated as reliable, sustainable and environmentally friendly. In recent years, the hemp plant has become the center of attention all over the world as a product with great potential. Hemp is a promising raw material for biofuel production because it has many advantages over other biomass. Important steps must be taken to cultivate this raw material. YOBÜ is a specialized university in the field of "**Industrial Hemp**" and is of great importance in bringing hemp biomass into the economy. The cannabis plant, from its root to its seed, is used in different applications in different industries. Hemp stalks and seeds are an excellent source of renewable energy. Hemp is an environmentally friendly and economical raw material that can be used for various bioenergy options. Hemp plant can contribute to our country and the world in the production of various types of biofuels (Bioethanol, biobutanol, biodiesel, super capacitor) by developing new production processes.

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İKLİM DEĞİŞİKLİĞİ İLE MÜCADELE VE EMİSYON HEDEFLERİ KAPSAMINDA TÜRKİYE'NİN NÜKLEER ENERJİ POLİTİKALARI ANALİZİ

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ÖZET

Küresel iklim değişikliğiyle mücadelede temiz enerjiye geçiş için fosil yakıt tüketimi dünya genelinde azaltılmakta ve fosil yakıtlar yerini temiz enerji kaynaklarına bırakmaktadır. Ancak, rüzgâr ve güneş gibi yenilenebilir kaynakların kesintili olması önemli kısıtlayıcı bir faktördür. Bu sebeple nükleer enerji, enerji güvenliğini sağlarken aynı zamanda iklim değişikliğiyle mücadele etmek amacıyla temiz enerji geçişinin temel bir taşıyıcısı olarak ortaya çıkmaktadır. Elektrik üretimi sırasında karbon salımı olmaması ve yaşam döngüsü emisyonlarının fosil yakıtlara ve bazı yenilenebilir kaynaklara göre daha düşük olması nedeniyle nükleer enerji, enerji dönüşümü politikaları için önemli bir seçenektir. Bu çalışmada, dünyada ve Türkiye'de enerji politikalarında nükleer enerjinin yeri iklim değişikliğiyle mücadele kapsamında incelenmiş ve bu incelemeler ışığında Türkiye'nin net sıfır emisyon hedefine ulaşmasında nükleer enerjinin rolünü belirlemek amacıyla bir analiz yapılmıştır. Analizler, sera gazı emisyonlarının minimizasyonuna dayalı üç senaryo içeren bir optimizasyon modeli üzerinden gerçekleştirilmiştir. Nükleer enerjinin Türkiye'nin enerji politikasında yer almadığı, mevcut durumdaki nükleer politikanın geçerli olduğu ve nükleer enerjiye ilişkin bir sınırlamanın yapılmadığı üç senaryo için elde edilen sonuçlar doğrultusunda politika çıkarımlarında bulunulmuştur.

Anahtar Kelimeler: Nükleer enerji, enerji politikaları, iklim değişikliği, karbon emisyonları, net sıfır emisyon

ANALYSIS OF TÜRKIYE'S NUCLEAR ENERGY POLICIES WITHIN THE SCOPE OF COMBATING CLIMATE CHANGE AND EMISSION TARGETS

ABSTRACT

In order to transition to clean energy in the fight against global climate change, fossil fuel consumption is being reduced worldwide and fossil fuels are being replaced by clean energy sources. However, the intermittency of renewable resources such as wind and solar is an important limiting factor. For this reason, nuclear energy emerges as a key carrier of the clean energy transition to combat climate change while ensuring energy security. Nuclear energy is an important option for energy transition policies because it has no carbon emissions during electricity production and its life cycle emissions are lower than fossil fuels and some renewable resources. In this study, the place of nuclear energy in energy policies in the world and Türkiye was examined within the scope of combating climate change, and in light of these examinations, an analysis was made to determine the role of nuclear energy in reaching Türkiye's net zero emission target. The analyses were carried out through an optimization model that included three scenarios based on the minimization of greenhouse gas emissions. Policy inferences were made in line with the results obtained for three scenarios in which i) nuclear energy is not included in Türkiye's energy policy, ii) the current nuclear policy is valid and ii)) there is no limitation on nuclear energy.

Keywords: Nuclear energy, energy policies, climate change, carbon emissions, net zero emissions.

1. Giriş

Fosil yakıt kullanımının artması ile dünyada iklim değişikliğinin beraberinde getirdiği endişeleri hafifletmek ve fosil yakıtların enerji üretimindeki paylarını azaltmak amacıyla, temiz enerji kaynaklarını içeren enerji karışımlarına yönelik bir gereksinim bulunmaktadır [1] [2]. Yenilenebilir kaynaklar kesintili enerji kaynakları olması sebebi ile enerji güvenliğini sarsmayacak bir temiz enerji dönüşümü için baz yük kaynaklara ihtiyaç duyulmaktadır [3]. Sera gazı salımına sebep olmadan elektrik üretimi sağlayan nükleer enerji, bu bağlamda ülkeler için önemli bir enerji kaynağıdır.

Literatürde nükleer enerjinin iklim değişikliği ile mücadeledeki rolüne ilişkin yapılmış çeşitli çalışmalar bulunmaktadır. Sovacool [4], Santayo ile Azapagic [5] ve Kharecha ile Hansen [6], çalışmalarında, Nükleer enerjinin sera gazı emisyonları üzerindeki etkisini diğer enerji kaynaklarıyla karşılaştırmakta, nükleer enerjinin düşük karbon ayak izine sahip olduğunu ve sera gazı emisyonlarının azaltılmasında önemli bir rol oynayabileceği sonucuna varmaktadırlar. Ayrıca Halkos ve Zisiadou [7] nükleer enerjinin güvenilir ve düşük karbonlu bir elektrik kaynağı sağlayabileceğini vurgulayarak, nükleer enerjinin iklim hedeflerine ulaşmaya çalışan ülkeler için önemli bir enerji kaynağı olduğunu belirtmiştir. Buongiorno ve arkadaşlarının [8] yapmış oldukları analizde ise düşük karbonlu enerji üretiminde meydana gelen tarihsel büyük ölçekli artışların en hızlı şekilde nükleer enerji ilavelerinin etkisi ile meydana geldiği gösterilmektedir.

Literatürde nükleer enerjinin Türkiye'nin iklim değişikliği ile mücadelesindeki rolüne ilişkin yapılmış çalışmalar da bulunmaktadır. Türkiye'de Nükleer Enerji Santrallerinin olumlu ve olumsuz yönlerini acil kaynak çeşitlendirmesi ihtiyacıyla ilişkilendirerek enerji güvenliği parametreleri üzerinden analiz eden Altundeğer [9] ve Topal Namlı [10], nükleer enerjinin Türkiye'nin ithal fosil yakıtlara bağımlılığını ve sera gazı emisyonlarını azaltmasına yardımcı olurken aynı zamanda enerji güvenliğini sağlayabilecek düşük karbonlu, temel yük bir enerji kaynağı olduğunu savunmaktadır. Korkmaz ve Önöz [11], rekabetçi pazarlarda fiyat oluşumunun arz ve talep eğrilerinin kesişiminde meydana geldiğini varsayan bir piyasa denge modeline dayanan çalışmalarında nükleer enerjinin Türkiye enerji sisteminde tamamlayıcı bir rol oynayabileceği, özellikle de temel yük gücü sağlayabileceği sonucuna varmışlardır.

Türkiye'nin giderek artan nüfusu nedeniyle enerji talebi ve bunun sonucunda elektrik üretimi, zaman içinde hızla artmaktadır. Ülkedeki elektrik üretim hacmi son 30 yılda beş katına çıkarak 334 TWh'ye yükselmiştir [12]. Elektrik talebinin gelecekteki on yılda ise 452 TWh'ye çıkacağı tahmin edilmektedir [13]. Net sıfır emisyon hedefleri doğrultusunda bu hızlı talep artışının mümkün olan en düşük karbon salımı ile karşılanması gerekmektedir. Türkiye'nin elektrik üretim portföyünü buna göre planlamak büyük bir öneme sahiptir. Bu kapsamda yapılan bir çalışmada Selçuklu ve arkadaşları [14] maliyetler, emisyonlar, ekonomik büyüme ve istihdam gibi faktörleri göz önünde bulundurarak, Türkiye'nin uzun dönem enerji sistem kapasitesi ve üretim genişleme stratejilerini analiz etmişlerdir.

Literatürde Türkiye'nin nükleer enerjinin net sıfır emisyon hedefine ulaşmasındaki rolünün optimizasyon yöntemleri ile incelenmesi konusunda eksiklik bulunmaktadır. Bu çalışmada ise literatürde ilk kez, sera gazı emisyonları minimize edilerek nükleer enerjinin bulunmadığı, mevcut durumdaki nükleer politikanın geçerli olduğu ve nükleer enerjiye ilişkin herhangi bir sınırlamanın yapılmadığı üç senaryo ile Türkiye'nin 2053 yılına kadar elektrik talebinin karşılanmasında maliyet ve emisyon durumları incelenmiştir. Elde edilen sonuçlar doğrultusunda, bu üç senaryoya ilişkin politika çıkarımları sunulmuştur.

2. METODOLOJİ

Türkiye'nin Paris İklim Anlaşması çerçevesinde 27. Taraflar Konferansında 693 Mt CO_2e salımını hedeflemiştir. Bugün Türkiye'nin toplam sera gazı emisyonlarının %32'si elektrik üretimi kaynaklıdır [15]. Bu durum dikkate alındığında Türkiye'nin elektrik üretiminden kaynaklanan emisyon miktarına ilişkin hedefi 222 milyon tona tekabül etmektedir. Türkiye'nin iklim değişikliği ile mücadelesinde nükleer enerjinin rolü ve net sıfır emisyon hedefine ulaşmadaki etkisi incelenen bu çalışmada, sera gazı emisyonlarını minimize etme mantığına dayalı bir optimizasyon modeli kurulmuştur. Matematiksel model ve optimizasyon yöntemi, Selçuklu vd.'nin [16] [14] çalışmalarından yararlanarak geliştirilmiştir. Matematiksel model, büyük ölçekli optimizasyon modellerinin çözümünde yaygın olarak kullanılan Genel Cebirsel Modelleme Sistemi (GAMS) kullanılarak doğrusal programlama modeli olarak kodlanmıştır.

Nükleersiz senaryo, mevcut durum senaryosu ve serbest nükleer senaryosu olmak üzere üç senaryo üzerinde çalışılmıştır. Nükleersiz Senaryo, Türkiye'nin mevcut politikalarının nükleer enerji kullanımını içermediği

düşünülerek, mevcut politika ve piyasa beklentilerine göre oluşturulmuştur. Mevcut Durum Senaryosu, Türkiye'nin mevcut enerji politikalarında yer alan Akkuyu NGS ve diğer iki nükleer santralin planlı aralıklarla devreye alınmasıyla ve Türkiye Ulusal Enerji Planı'nda [17] diğer kaynaklar için planlanan santraller de yıllarına göre hesaplamaya dahil edilerek oluşturulmuştur. Serbest Nükleer Kullanımı Senaryosu ise, nükleer enerji kullanımını herhangi bir sınırlama olmadan ele alarak 2053 yılında elektrik üretiminde net sıfır emisyon hedefine ulaşmak için gereken nükleer enerji üretim miktarının model tarafından belirlendiği bir senaryo olarak oluşturulmuştur.

Senaryolar, Türkiye'nin net sıfır hedeflerine ulaşma amacı doğrultusunda 32 yıllık bir planlama dönemi (2022-2053) üzerine odaklanmaktadır. Planlama sürecinde doğal gaz, yerli kömür, ithal kömür, nükleer, hidroelektrik, karaüstü rüzgâr, denizüstü rüzgâr, jeotermal, biyoenerji ve güneş enerjisi kaynakları dikkate alınmaktadır. Yıllık talep, başlangıç yılında (2022) 324,536 GWh olarak TEİAŞ'ın 10 yıllık talep tahmin raporlarından [13] elde edilmiş olup, planlama süresince yıllık ortalama talep artışı %3,8 olarak gerçekleşmektedir. Benzer şekilde, puant talep başlangıç yılında (2022) 56.537 MW olarak TEİAŞ'ın 10 yıllık talep tahmin raporlarından alınmış ve planlama süresince yıllık ortalama talep artışı %3,2 olarak gözlenmiştir.

Modelin amaç fonksiyonu (1), toplam sera gazı emisyonlarını en aza indirgemeye yöneliktir. Denklem (2) toplam maliyetin net bugünkü değerini hesaplar ve üretim (yakıt ve değişken işletme ve bakım) maliyeti (3), yatırım maliyeti (4) ve sabit işletme ve bakım maliyetinden (5) oluşur. Net bugünkü değer hesaplaması, girdi verilerinde ele alınır ve iskonto oranı, planlama ufku boyunca yılda %14'tür.

Tablo 1. Formülasyon İçin Terminoloji

Endeksler ve Kümeleri	
i, I	Üretim Birimleri
y, Y	Planlama yapılan yıllar
u	Planlama yapılan yıllar (y modellemede u olarak geçmektedir)
Karar Değişkenleri	
x_{yi}	i üretim biriminin y yılındaki üretim miktarı (MWh), sürekli değişken
s_{yi}	i üretim biriminin y yılındaki yatırım kapasitesi (MW), sürekli değişken
Parametreler (Girdiler)	
c_{yi}	y yılında i üretim birimi için üretim değişken maliyeti ($/MWh)
h_{yi}	Yeni nesil birim i için y yılında sabit işletme ve bakım maliyeti ($/MW)
a_{yi}	i üretim ünitesinin y yılındaki yatırım maliyeti ($/MW)
g_{yi}	y yılında mevcut üretim birimi i için sabit işletme ve bakım maliyeti ($/MW)
η_i	Üretim birimi i'den salınan CO_2 miktarı (CO_2/GWh)
r	Faiz oranı
γ_{yi}	i üretim biriminin y yılında planlanan yeni kapasitesi (MW)
θ_i	i üretim biriminin başlangıçta var olan kapasitesi (MW)
π	Yıllık saat (8760 saat)
δ_{yi}	i üretim biriminin y yılında yıllık inşaat limiti (MW)
p_i	Üretim birimi i için kapasite faktörü
d_y	y yılındaki talep (MWh)
d_y^p	y yılındaki en yüksek talep (MWh)
m	Rezerv marjı yüzdesi (oran) (%10)

$$\min Emissions = \sum_y \sum_i x_{yi}\eta_i \quad (1)$$

$$Cost = \sum_y (C_1 + C_2 + C_3) \quad (2)$$

$$C_1 = \sum_i x_{yi}\, c_{yi} \quad (3)$$

$$C_2 = \sum_i s_{yi}\, a_{yi} \quad (4)$$

$$C_3 = \sum_i \left(\sum_{u=1}^{y} (s_{ui} + \gamma_{yi})\right) h_{yi} + \sum_i \theta_i\, g_{yi} \quad (5)$$

Arz-talep kısıtı (6), modelin tüm birimlerinin üretimlerinin toplamı ile toplam yıllık elektrik talebinin karşılanmasını sağlar. Kapasite kısıtlaması (7), modelin mevcut ve inşa edilmiş kapasitenin üzerinde elektrik üretemeyeceğini belirtir. Rezerv (yedek) kapasite gerekliliği (8), mevcut ve kurulu kapasitenin en yüksek talep kapasitesi artı rezerv kapasiteden büyük veya ona eşit olmasını şart koşarak üretim yeterliliğini sağlar. Son kısıtlar, her bir üretim biriminin yıllık inşaat limiti (9), nükleersiz senaryo için nükleer yatırım limiti (10) ve negatif olmama kısıtıdır (11).

$$\sum_{i} x_{yi} \geq d_y \; \forall y \tag{6}$$

$$x_{yi} \leq \left(\theta_i + \sum_{u=1}^{y} s_{ui}\right) \pi p_i \; \forall y \tag{7}$$

$$\sum_{i} \theta_i + \sum_{u=1}^{y} \sum_{i} s_{ui} \geq d_y^p m \; \forall y \tag{8}$$

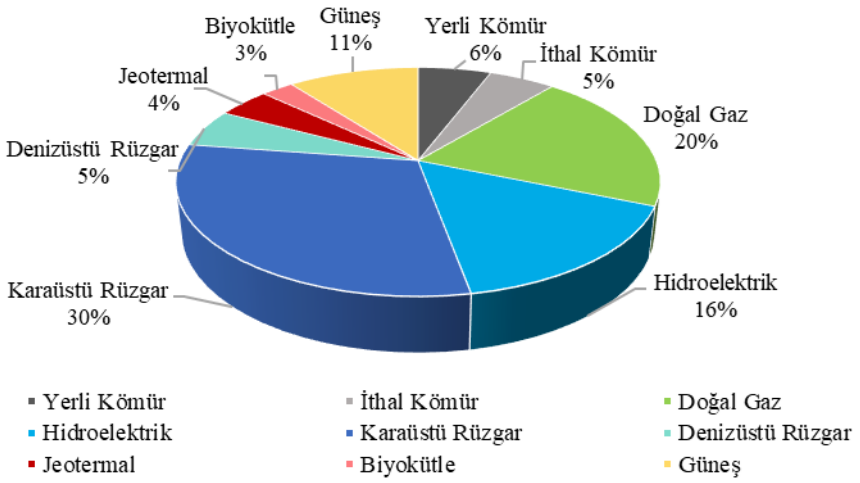
$$s_{yi} \leq \delta_{yi} \; \forall y \tag{9}$$

$$s_{y,nuc} = 0 \tag{10}$$

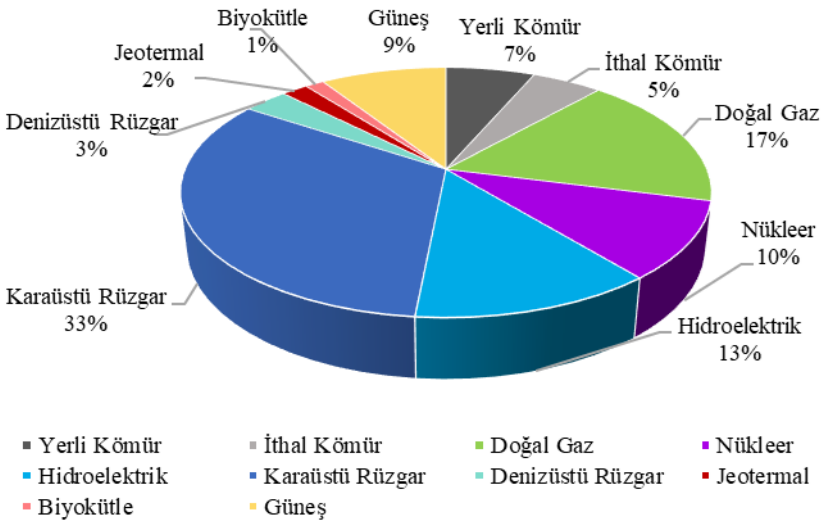
$$x_{yi}, s_{yi} \geq 0 \tag{11}$$

3. BULGULAR

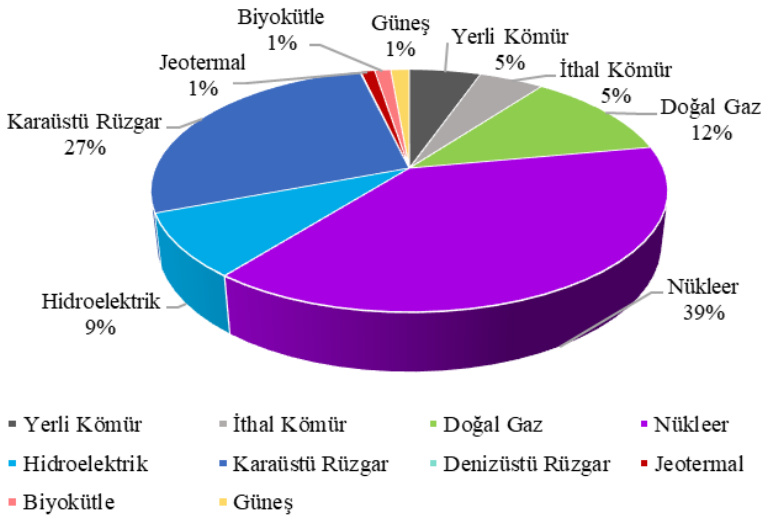
Minimum emisyon mantığına dayalı modelin 2053 yılına ilişkin elektrik üretim payları Şekil 5, 6 ve 7'de yer alan grafiklerde gösterilmektedir. Model, elektrik üretiminde tüm senaryolarda yerli ve ithal kömür kullanımını, düşük yaşam döngüsü emisyonlarına sahip kaynaklara göre daha düşük bir payda tercih etmiştir. Nükleersiz senaryo ile mevcut durum senaryosu sonuçları karşılaştırıldığında, üç nükleer santralin devreye girmesi ile hidroelektrik, doğal gaz, güneş ve deniz üstü rüzgâr santrallerinin payının sınırlı bir şekilde azaldığı gözlemlenmektedir. Şekil 7'de görüldüğü gibi, serbest nükleer senaryosunda nükleer enerjiye dair herhangi bir kısıtlama olmaması ve daha düşük yaşam döngüsü emisyonlarına sahip olması nedeniyle nükleer enerji diğer kaynaklara göre daha fazla tercih edilmiştir. 2053 yılında Türkiye'nin elektrik üretiminde nükleer enerjinin yüksek bir paya sahip olmasının başka bir nedeni, güneş, rüzgâr ve hidroelektrik gibi yenilenebilir kaynaklara göre nükleer enerjinin daha yüksek bir kapasite faktörüne sahip olmasıdır.



Şekil 5. Nükleersiz Senaryo, Elektrik Üretim Payları, 2053



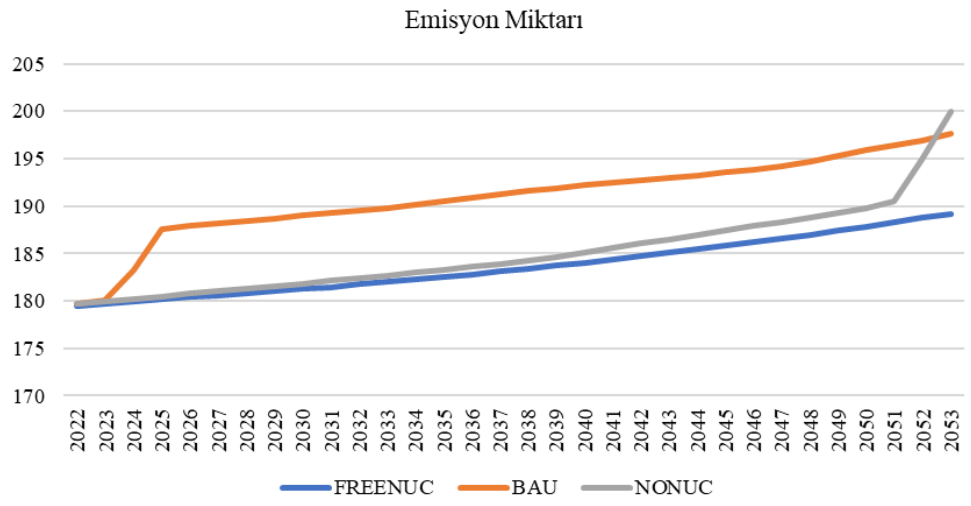
Şekil 6. Mevcut Durum Senaryosu, Elektrik Üretim Payları, 2053



Şekil 7. Serbest Nükleer Senaryosu, Elektrik Üretim Payları, 2053

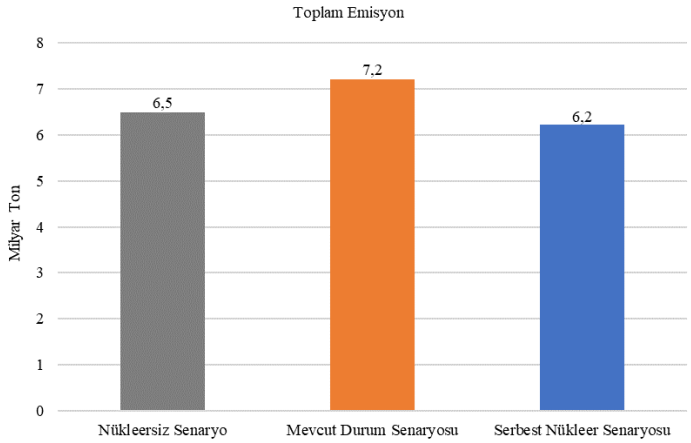
Türkiye'de artan enerji talebini karşılamakta olan kömür ve doğal gaz gibi fosil yakıtların yanı sıra hidroelektrik, güneş, rüzgâr, jeotermal enerji gibi yenilenebilir enerji kaynaklarının ve nükleer enerjinin de her biri sahip oldukları farklı emisyon değerleri sebebi ile ülkenin sera gazı emisyonlarının artmasına sebep olmaktadır. Yaşam döngüsü emisyonları olarak adlandırılan bu emisyon değerleri; malzeme, madencilik, inşaat, kurulum, işletme ve atık yönetimine kadar kaynağın tüm ömrünü kapsayacak şekilde hesaplanmaktadır.

Türkiye'nin artan enerji talebini minimum emisyona yol açacak şekilde karşılama mantığına dayalı yapılan modellemede nükleersiz senaryo, mevcut durum senaryosu ve serbest nükleer senaryosuna ilişkin emisyon değerleri Şekil 8'de gösterilmektedir. Grafikte yer alan yıllara göre emisyon değerlerinde serbest nükleer senaryosundaki emisyon salımının diğer senaryolara göre daha az miktarda olduğu görülmektedir. Ulusal Enerji Planında 2030 yılına kadar devreye girmesi planlanan yerli kömür ve 2035 yılına kadar devreye girmesi planlanan doğal gaz santrallerinin mevcut durum senaryosunda dikkate alınması sebebi ile emisyon miktarında hızlı bir artış meydana geldiği ve bu farkın kurulması planlanan üçüncü nükleer santralin tüm ünitelerinin elektrik üretmeye başlaması ile 2053 yılına doğru kapandığı ve mevcut durum senaryosuna ait emisyon miktarının ilerleyen yıllarda nükleersiz senaryonun altında kalacağı anlaşılmaktadır.



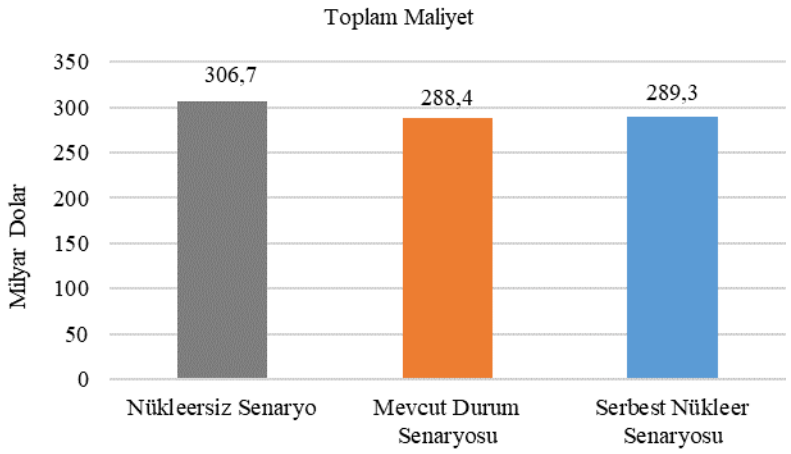
Şekil 8. Nükleersiz Senaryo, Mevcut Durum ve Serbest Nükleer Senaryosunda Türkiye'nin Yıllara Göre Sera Gazı Emisyon Değerlerinin Karşılaştırılması

Planlanan yıllar için senaryo bazlı toplam emisyon miktarları Şekil 9'da yer alan grafikte gösterilmektedir. Mevcut durum senaryosuna ait toplam emisyon miktarı değeri, diğer iki senaryonun değerlerine göre daha yüksektir. Aradaki farkı oluşturan temel sebeplerden biri 2035 yılına kadar devreye girecek olan fosil kaynaklı santrallerdir.



Şekil 9. Planlanan Yıllar (2022-2053) İçerisindeki Toplam Emisyon Miktarları

Minimum emisyon mantığına dayalı üç senaryo için toplam maliyet sonuçları Şekil 10'daki grafikte yer almaktadır. Mevcut durum senaryosunun toplam maliyeti diğer iki senaryoya göre daha düşük çıkarken, düşük emisyonlu elektrik üretiminde en yüksek mali yükü nükleersiz senaryonun getirdiği görülmektedir.



Şekil 10. Senaryoların Planlanan Yıllar İçindeki Toplam Maliyetleri

Üç senaryonun sonuçları karşılaştırıldığında nükleer enerjinin yenilenebilir kaynaklarla birlikte kullanımının emisyon azaltımında pozitif yönde katkı sağladığı değerlendirilmektedir. Planlanan dönem içerisinde (2022-2053) mevcut durum senaryosunda fosil kaynaklı santrallerin devreye girmesi sebebi ile diğer iki senaryoya göre daha düşük maliyetle elektrik üretimine imkân sağlamış olsa da emisyon değerleri diğer iki senaryoya göre daha yüksektir. Model tarafından fosil kaynaklar yerine yenilenebilir kaynakların yoğunlukla tercih edildiği nükleersiz senaryoda ise emisyon açısından mevcut durum senaryosuna göre daha olumlu sonuç alınsa da maliyet açısından tüm senaryolar içinde en verimsiz sonucu vermiştir.

4. SONUÇ VE TARTIŞMA

Türkiye'nin Paris İklim Anlaşmasına yönelik beyanında en net hedeflerin enerji sektöründe sera gazı emisyonlarının azaltılmasına yöneliktir. Bu çalışmada da nükleer enerjinin Türkiye'nin iklim değişikliği ile mücadelesinde hedeflerine ulaşmasındaki rolünü incelemek için sera gazı emisyonlarının minimize edilmesi mantığına dayalı bir optimizasyon modellemesi üzerine çalışılarak minimum emisyon ile elektrik santralleri yatırım ve üretiminin maliyeti hesaplanmıştır. Modelde nükleer enerjinin olmadığı, üç nükleer santralin mevcut olduğu ve nükleer santraller için sınırlama olmadığı üç farklı senaryonun emisyon ve maliyet etkileri incelenmiştir. Senaryolar içinde en yüksek emisyon değeri devreye girmesi planlanan fosil yakıt kaynaklı kurulu güçler sebebi ile mevcut durum senaryosunda çıkmıştır. Bu senaryoda yer alan nükleer santrallerin uzun aralıklarla devreye girmesi varsayımı da emisyon değerlerinin yüksek çıkma sebeplerinden biridir. Serbest nükleer senaryosunda ilk yıldan itibaren nükleer santral devreye alınarak ileriki zamanlarda da yeni nükleer santral kurulumlarına devam edildiği görülmektedir. Aynı zamanda mümkün olan minimum emisyon salımı ile elektrik üretiminin, nükleer enerjisiz mali açıdan daha fazla yük getirdiği sonucuna varılmıştır.

Modellemede yer alan senaryo sonuçları içinde en yüksek emisyon değerine sahip olan mevcut durum senaryosunun 2030 yılına ilişkin emisyon değeri 210,6 milyon ton ile hedefin altında bir gerçekleşme sağlarken diğer iki senaryonun emisyon miktarı da hedeflenen seviyenin oldukça altındadır. Bu durumda Türkiye'nin üç senaryoya göre de Paris İklim Anlaşması kapsamındaki 2030 yılına ait hedefini gerçekleştireceği öngörülmektedir. 2053 yılı için ise Türkiye'nin doğal yutak hacmi göz önünde alındığında hedeflenen net sıfır emisyon değeri 121 milyon ton CO_2e olması gerekmektedir [18]. Elektrikli araçların kullanımının yaygınlaşması ve konutlarda elektrifikasyonun artması sebebi ile elektrik üretimi kaynaklı sera gazı emisyonlarının yaklaşık %40'a yükseleceği varsayımı ile Türkiye'nin 2053 net sıfır hedefine ulaşılması için elektrik üretiminden kaynaklanan emisyon miktarının yaklaşık 48 Mt CO_2e değerinde olması gerekmektedir. 2053 yılı emisyon miktarları üç senaryo için de gözden geçirildiğinde en düşük emisyona sahip serbest nükleer senaryosunda salınan emisyon miktarının hedeflenenden yaklaşık 152 Mt CO_2e daha fazla olduğu sonucuna varılmaktadır. Bu durum Türkiye'nin net sıfır hedefi doğrultusunda nükleer enerjiye önemle ihtiyaç duyulmasına karşın nükleer santral kurulu gücü için herhangi bir sınırlama yapılmasa dahi net sıfır hedefine ulaşmak için yeterli olamayabileceğini göstermektedir. Tüm senaryolarda 2053 yılı net sıfır emisyon hedefine ulaşılamaması ise Türkiye için enerji verimliliğinin önemini ortaya çıkarmaktadır.

KAYNAKÇA

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ENHANCING PERFORMANCE OF PRINTED CIRCUIT BOARD AXIAL FLUX PERMANENT MAGNET MACHINES (PCB-AFPMM) THROUGH HEAT SINK INTEGRATION

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ABSTRACT

Printed Board Circuit (PCB) Axial Flux Permanent Magnet Machines are increasingly popular due to their reliability, robustness and easy manufacturing. PCB stator allows to bypass time taking and complex winding manufacturing process and simplifies the manufacturing process of AFPM machines as well as it helps to increase the durability and reduce the weight of machine although the heat generated from the losses of motor is critical for PCB AFPM machines. The research aims to design, simulate and prototype PCB AFPM and heat-sink for PCB AFPM machine for thermal management of PCB AFPM machine. Considering the motor losses, it was possible to size a heat sink so that it could be applied on the stator and to dispose of a total of 10 W of thermal power. The geometry used for the design of the fins is circular arc and allows both to maximize the exchange surface and to increase the stiffness of the fins. Finally, the heat sink was numerically simulated with Ansys Students verifying that it satisfies the criteria for which it was designed.

Keywords: PCB, AFPM, Thermal management.

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Introduction:

Printed Circuit Board PCB axial flux permanent magnet machines AFPMMs represent a significant advancement in electric machine design offering several advantages over traditional configurations. The use of printed circuit board (PCB) stators contributes for the durability and efficiency of production of these machines, and they're popular for their simplified designs and robustness.

Since PCB stators are intrinsically robust, manufacturing becomes simpler and the machines remain safe from mechanical stresses. The mechanical strength and ease of manufacturing of PCB-AFPMMs are highlighted in literature. In addition to their mechanical advantages, PCB-AFPMMs present significant advantages for a number of industries, such as the automotive and renewable energy sectors[1][2][3].

Their high power-density and compact size not only improve performance but also support the global hunt for sustainable energy alternatives.Although PCB-AFPMMs have many benefits, mitigating thermal issues remains crucial for maximizing their efficiency.

Optimizing the efficiency and reliability of PCB-AFPMMs requires an understanding their thermal characteristics. The thermal behaviour of these machines in different working situations requires the use of

intelligent thermal management techniques. As a result, this paper seeks to investigate the heat sink technology integrated into PCB-AFPMMs, highlighting its critical role in reducing thermal issues. By merging advances in thermal dynamics and electromagnetics, this research intends to show how heat sink integration can significantly improve the performance, reliability, and efficiency of PCB-AFPMMs. Utilizing the durability, simplified manufacturing processes using PCB stators, and effective thermal dissipation techniques, this research aims to make a contribution to the development and broad use of PCB-AFPMMs in today's technological environments.

An important component of an electric motor thermal management system, a heat sink dissipates the heat produced during operation. [4] To achieve this, the heat is transferred to a fluid medium, either air or liquid coolant, which subsequently removes the heat from the motor. For electric motors to achieve high power density and effective heat dissipation, heat sink design, and adjustment are important [5]. The two primary methods of air-cooling heat sinks are forced convection and natural convection. [6] While forced convection uses external devices, like fans to enhance the transfer of heat, natural convection relies on the free flow of air over the heat sink to disperse heat. The choice of these approaches depends on the specifications of motor and amount of heat generated by the motor.

The differences between natural and forced convection heat sinks lie in the driving mechanisms, rate of heat transfer, and control and regulation While forced convection uses external sources to generate fluid motion and makes an externally regulated, generally higher rate of heat transfer, natural convection is caused by density and temperature gradients and results in unaided fluid motion [7]. The research intends to build and integrate a heat sink for improved efficiency by dissipating the thermal energy needed to keep the motor at the working temperature, considering the maximum operating temprature of motor to be 40 °C.

PCB AFPM Machine Parameters:

A two Phase wave winding PCB AFPM motor with high no. of pole pairs and high frequency supply is used for the research. The parameters and date of Motor are taken from [8]. Parameters are mentioned in Table no.1

Table no.1

Parameter	Value
Rated current	4.5 A
Rated voltage	7 V
Rated frequency	1.8 kHz
Number of phases	2
Number of poles	48
Outer radius	80 mm
Inner radius	40 mm
Magnet length	14 mm
Magnet thickness	1.5 mm
Stator thickness	5 mm
Copper thickness	0.104 mm
PCB thickness	200 μm
Air gap	1.2 mm
Winding type	Wave type with two conductors per pole per phase

CAD design of PCB AFPMM and Heat Sink:

The motor consists of 48 poles and two phase wave winding. CAD design of motor is given in Fig.1

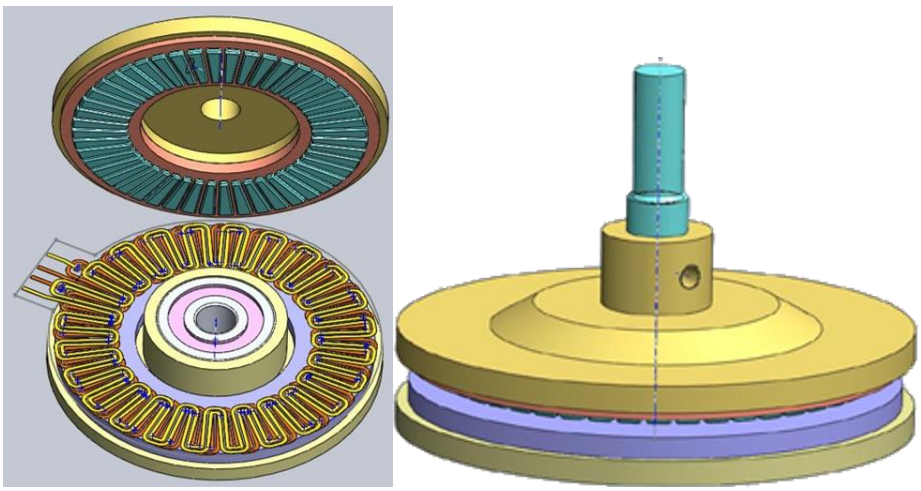


Fig.1 CAD design of PCB AFPMM

As the heat sink will be mounted at the back of the stator core, hence the heat sink design is selected on the basis of compatibility with stator yoke of the machine. Most effective heat sink design is the design with more surface area, which can be achieved by making more fins of heat sink as well as making turned and twisted fins to enlarge the surface area of fins[9][10]. The geometry of the heat sink was created with a circular base with a thickness of 5 mm, while the height of the fins is equal to 25 mm, for a total of 40 fins, with a thickness of the fin equal to 3 mm. CAD design of heat-sink is given in figure 2. Fins of the heat sink are twisted to enhance the surface area, hence the capability of the heat sink to evacuate heat. Combined CAD design of the motor is shown in Figure 3, which shows the heat sink mounted at the back of the stator yoke.

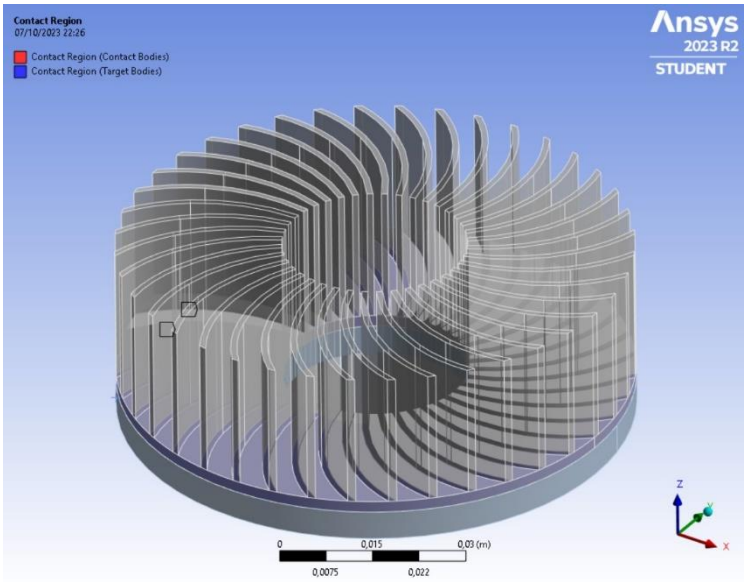


Fig.2 Heat-Sink Design

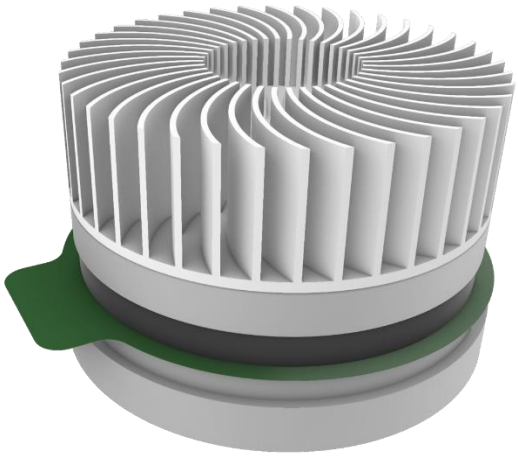


Fig.3 Heat-Sink mounted at the back of the Stator yoke

Thermal Analysis:

The thermal Steady state analysis was performed using Ansys student Workbench and provides a first verification of the problem based on Newton's heat transfer model: $\dot{Q} = h_c A(T_s - T_\infty)$

Where $\dot{Q}$ is the thermal power, h_c is the heat transfer coefficient, A is the surface area where the heat transfer takes place, T_s is the temperature of the surface and T_∞ is the temperature of the air.

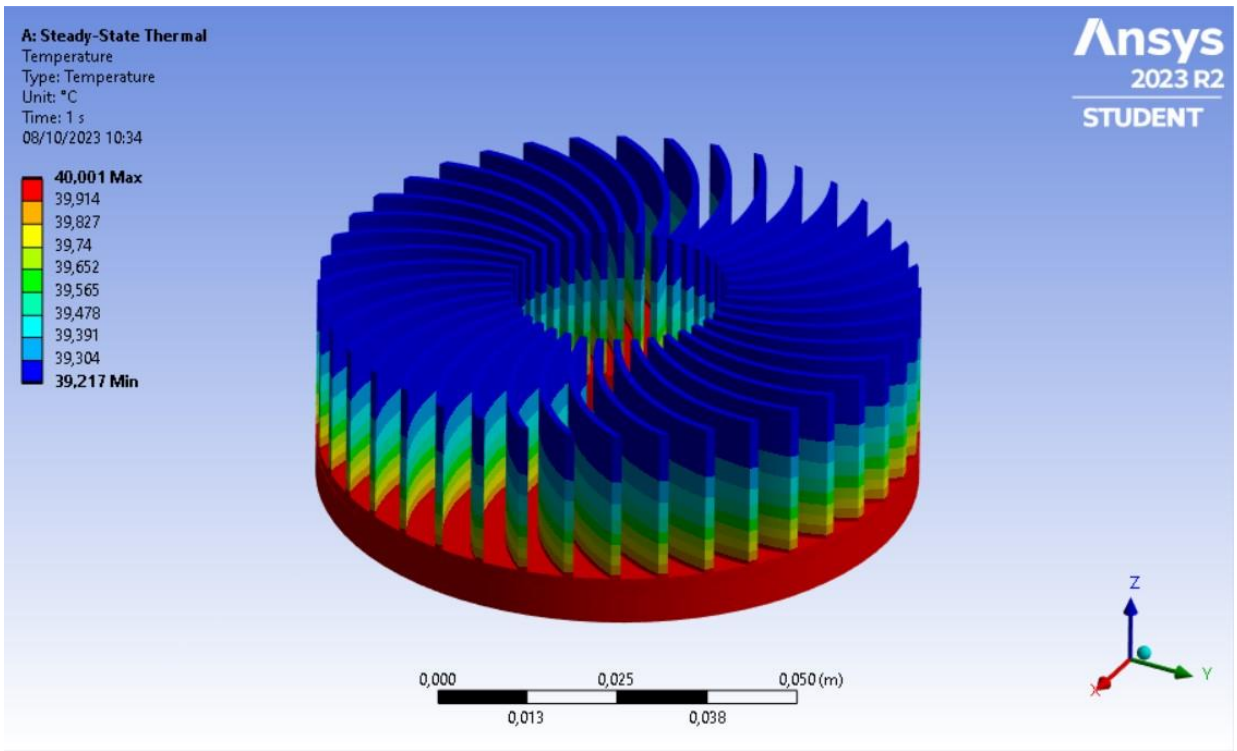
Other information can be found on Ansys documentation [11]. The boundary conditions imposed in the simulation were: a contact region between the top of the engine and the lower part of the base of the heat sink, the rest of the finned system was simulated taking into account a natural convection boundary condition applied with a geat transfer coefficient equal to $10\frac{W}{m^2K}$, the temperature of the imposed air is 22 °C.

In the simulations we found that the maximum thermal power that we need to dissipate is around 5 W, but we consider an overload of the motor so for safety we suppose 10 W of thermal power dissipated.

For this reason, we placed ourselves in the limit condition of an engine temperature equal to 40 °C and, in this condition, it was possible to verify whether the heat sink could dissipate a power equal to or greater than the 10 W estimated in the case of overload.

Simulation Results:

With a constraint of maximum 40 °C temprature of the motor, Heat sink allows us to dissipate 12.58 W of thermal power, consequently higher than the power required by the machine, this indicates that the heat sink is correctly sized to the purpose.



Future Work:

Two phase wave winding 48 pole, high frequency PCB AFPMM has been prototyped by F. Marignetti et. al and and data used in the research is from [8]. Research intends to practically test the motor thermal management using designed heat sink. Fig.5 shows the prototype tested in [8] without heat sink.

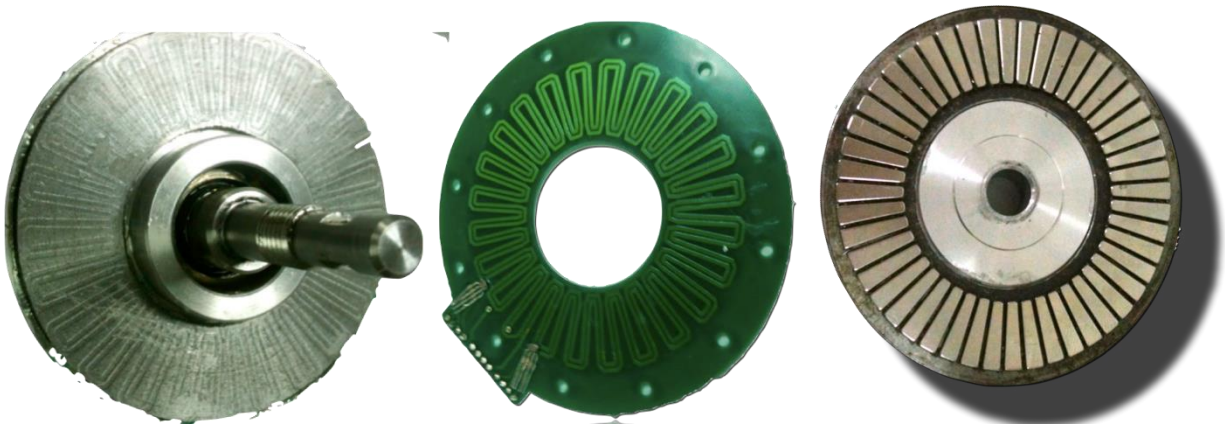


Fig. 8. PCB AFPMM prototype: SMC staor core; PCB two phase wave winding; NdFeB PM Rotor

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EVALUATION OF THE SOLID PRODUCT OBTAINED FROM PLASTIC WASTE PYROLYSIS IN ALTERNATIVE FUEL PRODUCTION

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ABSTRACT

Pyrolysis is an important thermochemical process that can be used in waste disposal and produces valuable products in solid, liquid and gaseous form at the end of the process.

Within the scope of this study, it is aimed to use the solid product, which is one of the pyrolysis by-products, as an adsorbent in the purification of pyrolysis gas. In addition, the usability of pyrolysis solid, which is a new waste produced after pyrolysis gas purification, as an alternative solid fuel, was investigated. With experimental studies carried out in this direction, pyrolysis processes of PP type plastic waste were carried out at target temperatures of 500°C, 600°C and 700°C, respectively. The solid product (char) obtained from these pyrolysis processes was activated and compared with activated carbon (AC), which is the most important adsorbent in practice. Afterwards, the adsorption efficiency of this adsorbent and the gaseous product obtained from the pyrolysis of the relevant plastic type was examined with analytical methods.

As a result of the study, in the adsorption of waste PP pyrolysis gas product; Again, adsorption efficiencies of 40-80% were obtained with the adsorbent obtained from waste PP pyrolysis solid. In the adsorption columns created from pyrolysis char, the components that PP type activated char adsorbed with the highest efficiency in adsorption of pyrolysis gases were toluene, styrene and styrene, respectively, at 500°C, 600°C and 700°C. When an evaluation was made with the BET analysis results, an approximately 20-fold increase in the adsorption efficiency was observed in the surface area of char species with the activation method, compared to their non-activated state. PP char, which is a secondary waste obtained as a result of the adsorption process, was recovered and its C, S and N contents and calorific values were investigated. As a result, among the adsorbents used in the adsorption process, activated char obtained at 700°C has become the most suitable alternative fuel in terms of calorific value and emissions as a result of combustion.

With this study, an alternative way is presented for the use of char, one of the by-products resulting from the disposal of plastic waste by pyrolysis method, while pyrolytic gas, which is another pyrolysis product and known to have toxic properties, is treated with pyrolysis solid. At the end of the treatment study, the solid product formed was recovered and its usability as an alternative fuel was demonstrated.

Keywords: Adsorption, alternative fuel, plastic waste, pyrolysis, solid product.

Introduction

Industrial developments have brought many innovations to the benefit of humanity, especially in terms of material technology. Plastics, discovered by chance in the late 19th century, are one of them. Plastics, which are used as alternatives to different materials in many sectors, are divided into two according to their structure and production methods. These types, called thermoplastic and thermoset, are grouped under different headings (Ay, 2013). Plastics consist of hydrocarbons and occur as petroleum products. They also contain additives such as colorants and strength enhancers, which are considered environmental pollutants and have toxic properties (Brems et al., 2012).

Due to its permanence properties and high polluting effects, plastic pollution has been called "the most important environmental problem of our world" (Environment, 2018). Plastics, the type of waste that accumulates most in urban solid waste areas, are highly polluting and have a high potential to harm the ecosystem due to the mentioned properties, but they also have recyclable properties. In addition to reducing the environmental damage of plastic waste through various recovery or recycling processes, creating economic

value again is a popular phenomenon. The most commonly used methods today for the disposal or recovery of plastic waste are; storage and incineration processes. These processes have various disadvantages in terms of cost, technology, space requirement, security and environmental issues. These methods, which are not efficient in terms of recovery and recycling, can be considered as classical methods that are losing their importance in the disposal of plastics, which are petroleum products, considering that the oil reserves, our most important energy source in the world, are decreasing.

Transforming plastic waste into more economically valuable and useful chemicals has been one of the most studied topics in recent years, and pyrolysis is a prominent method among these. Pyrolysis, long chain organic substances; It can be expressed as a process in which thermal decomposition occurs in an oxygen-free environment. This process enables the relatively longer chains of organic substances subjected to pyrolysis to be broken down into shorter chain molecules that become smaller and less complex as a result of controlling the heat value and pressure of the process (Qinglan et al., 2010). Moreover, the solid, liquid and gas products obtained after the reaction have various usage areas. This is an indication of the compatibility of the pyrolysis method with the minimum waste, or as it is popularly known today, zero waste approach.

It is seen that studies on the pyrolysis process often focus on liquid products that have fuel value, and similarly, they do not focus on gaseous products that have fuel value but do not exhibit stability and have negative environmental effects, and solid decomposition materials that may have many uses. Char, which is the solid product of pyrolysis, is a porous structure, rich in carbon and containing many inorganic compounds (Bernardo et al., 2012). This situation makes the evaluation possibilities of solid product essential. Gas pyrolysis decompositions are pyrolysis parameters that are important to examine, including their character, economic value, negative effects on the environment and global warming, and their purification. In order for the pyrolysis method to be more sustainable and economical, gas and solid products must also be specifically evaluated.

Within the scope of the study, the disposal of polypropylene (PP) plastic wastes at different pyrolysis temperatures was carried out under laboratory conditions. The gaseous product resulting from the pyrolysis experiments was adsorbed onto the solid product (char) of the system resulting from the pyrolysis process. For comparison purposes, the same gas adsorption experiments were carried out with commercial powder AC. Finally, the fuel value of waste adsorbents used in adsorption was investigated.

Materials and Methods

PP type thermoplastic wastes used in the study were obtained from the Municipal Solid Waste Separation center. A laboratory-scale waste shredding machine was used to shred PP type plastic waste. The pyrolysis system consists of furnace, reactor liquid capture vessels, nitrogen tube and gasometer parts, and these parts are shown in detail in Figure 1.

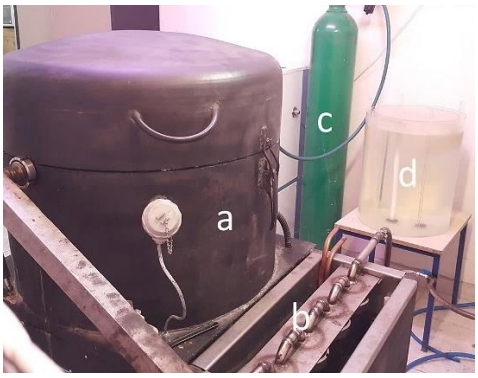


Figure 1. Pyrolysis system: a. Oven and reactor, b. Condensation caps, c. Nitrogen tube, d. Gasometer

BET analysis was preferred in determining the surface area properties of char materials to be used as adsorbents in the study. BET analysis within the scope of the study was carried out with the Quantachrome-Quadrasorb Evo 4 brand and model device. High resolution images of activated and unactivated pyrolysis cocci were taken with SEM. Imaging was carried out by placing it on a Zeiss brand EVO-LS10 scanning electron microscope.

Gas product compositions formed after pyrolysis were determined by gas chromatography (GC-MS) analysis.

PP type plastic wastes were subjected to pyrolysis at target temperatures of 500, 600, and 700 °C. Plastic wastes, weighed in certain proportions and recorded, were placed in the pyrolysis reactor. Pyrolysis was carried out in a system adjusted to provide 5°C heating per minute. While the pyrolysis solid product chars were obtained from inside the reactor, the condensed pyrolysis liquid product was collected from the liquid capture containers and the pyrolysis gas product was collected in the gasometer. In the later stages of the study, pyrolysis cocci were subjected to a three-step activation process to be used in adsorption experiments, and literature research was taken as reference in selecting this process (Dertli, 2004; Karacan and Karacan, 2014). In the activation method, impregnation was applied to the char samples with the prepared KOH solution.

To conduct adsorption experiments, columns were prepared using 1 g of activated and non-activated chars for each experiment. Glass materials with a diameter of 1 cm were used in column preparation. The prepared columns were connected to the system outlet to draw gases of known quantity and volume collected in the gasometer connected to the pyrolysis system. After adsorption, the columns were closed and stored at -18 °C until extraction and GC-MS analysis of the compounds they adsorbed. The calorific value, nitrogen, sulfur, oxygen and moisture values of the waste adsorbent char formed after the adsorption process were measured and compared with coal.

Findings and Discussion

Pyrolysis product yields are shown in Table 1. As the pyrolysis temperature increased, that is, from 500°C to 700°C, the amount of plastic char decreased and the gas product yield decreased. Accordingly, the amount of liquid products decreased. As the pyrolysis temperature increases, depolymerization increases and gasification continues.

Table 1. Product Yields Obtained as a Result of Pyrolysis Experiments (for 100 g of waste plastic)

Temperature (°C)	Heating Rate (°C/min)	Char (g)	Liquid (g)	Gase (g)
500	5	4.8	64.4	53.8
600	5	4.27	52.3	43.43
700	5	4.17	58.1	37.72

BET analysis results of raw pyrolysis char (non-activated), activated pyrolysis char and used commercial powder AC for comparison purposes are given in Table 2. The surface area of the char of plastic wastes in their non-activated state was 12-13 m^2/g, and after activation, it increased to 250-515 m^2/g. It was achieved to significantly increase the adsorption capacities of activated and non-activated char by increasing the surface area values by 20 times. This increase in surface area is also observed in micropore and total pore volume at similar rates for char.

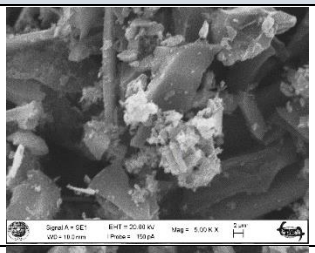
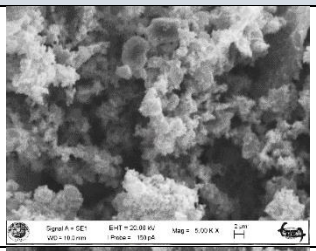
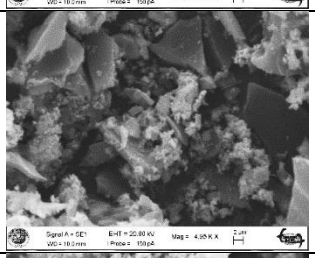
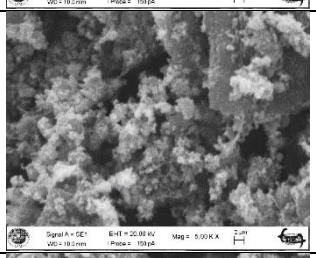
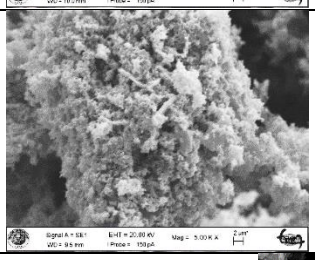
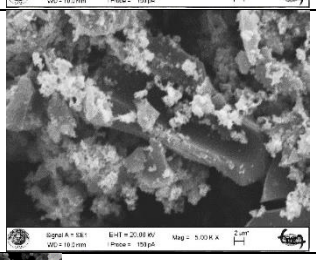
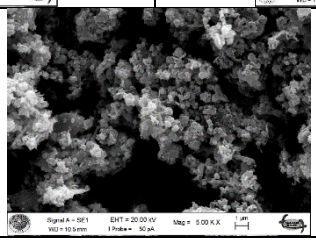
Table 2. BET Analysis Results for Activated, Non-Activated Chars and Reference AC

	Sample	Surface Area (m^2/g)	Micropore Volme (cc/g)	Total Pore Volume (cc/g)
Non-activated	**PP500**	12.10	0	0.0028
	PP600	11.39	0	0.0030
	PP700	13.25	0	0.0033
Activated	**PP500**	250.91	0.11	0.2047
	PP600	203.91	0.09	0.1690
	PP700	515.41	0.27	0.3931
Activated Carbon (AC)		668.23	0.35	0.5067

SEM images of activated and non-activated char obtained from the pyrolysis of PP type plastic waste are given in Table 3. It can be seen that the activation method shows the highest efficiency at 500°C. The most intense

morphological transformation between the non-activated and activated state is displayed here. The reason why the highest activation efficiency is at this temperature is the change in the topography of the non-activated char as the target temperature increases. The porosity of the non-activated char structure as the pyrolysis target temperature increases is an indication that the char structurally approaches AC at high temperatures other than the activation method. However, this poration is not as intense as that obtained with the activation method.

Table 3. SEM Images of Non-Activated and Activated Pyrolysis Chars (x5000)

Sample	Non-activated	Activated
PP 500		
PP 600		
PP 700		
AC		

To determine the adsorption efficiency, the adsorption of some alkane and alkene group compounds selected as pentane, hexane, benzene, toluene, octane, ethylbenzene and styrene was monitored.

The gas concentrations held in non-activated char, activated char and activated carbon columns obtained from adsorption experiments are given in Table 4. An average of 10-25% of the gas component concentrations can be retained in adsorption columns consisting of unactivated char. In general, it has been observed that pyrolysis chars obtained at high pyrolysis temperatures adsorb the gas components specified in the table at higher efficiency. As the pyrolysis temperature increases in activated columns, the trapped gas concentrations also increase. The retention efficiencies of gaseous products held in activated char columns for all types; It is seen that it increases from 11.5-12% to 40-90% (Table 5). This is an efficient indicator of the activation method.

Table 4. Gas Concentrations Adsorbed in Non-Activated Char Columns

Compound	Raw Gas Concentration (µg/L)			Gas Concentration Adsorbed in the Column (Non-activated) (µg/L)		
	500°C	600°C	700°C	500°C	600°C	700°C
Pentane	934.55	987.63	1052.13	121.96	188.42	177.23
Hexane	55.08	56.74	59.27	15.23	16.23	13.41
Benzene	43.01	44.96	47.31	4.01	12.70	11.90
Toluene	16.29	15.42	17.16	5.56	6.12	5.99
Octane	19.71	18.42	20.83	4.78	8.70	36.80
Ethylbenzene	5.27	5.42	5.52	1.54	1.42	2.86
Styrene	14.10	14.42	14.84	0.79	1.60	3.63

Table 5. Gas Concentrations Adsorbed in Activated Char Columns

Compound	Raw Gas Concentration (µg/L)			Gas Concentration Adsorbed in the Column (Activated) (µg/L)		
	500°C	600°C	700°C	500°C	600°C	700°C
Pentane	934.55	987.63	1052.13	394.45	592.23	815.63
Hexane	55.08	56.74	59.27	34.88	41.53	42.13
Benzene	43.01	44.96	47.31	17.45	21.6	29.42
Toluene	16.29	15.42	17.16	12.23	11.52	14.19
Octane	19.71	18.42	20.83	10.50	13.52	14.2
Ethylbenzene	5.27	5.42	5.52	1.56	3.28	5.17
Styrene	14.10	14.42	14.84	5.07	12.23	13.92

Activated and non-activated chars and AC were used as adsorbent in the adsorption of pyrolysis gases. By partially purifying the pyrolysis gas with these adsorbents, a new evaluation area for the pyrolysis char is proposed. It is also important to recover the adsorbents (waste adsorbents) used in the adsorption process in accordance with the zero waste approach. The calorific values of these waste adsorbents were investigated and their usability as an alternative fuel to coal was investigated. Calorific values and proximate and ultimate analyzes of waste adsorbents are given in **Table 6**. The results were compared with the analysis results of Tuncbilek coal produced in Turkey (Wikipedia 2022; Kemal 2004).

Table 6. Proximate and Ultimate Analyses of Waste Adsorbents

Parameter	Pyrolysis Temperature (°C)	Waste non-activated PP char adsorbent	Waste activated PP char adsorbent	Waste AC adsorbent	Coal
Calorific Value (cal/g)	500	4821.60	5035.80	5381.25	5062
	600	5098.80	5150.25	5350.80	
	700	5169.15	5201.70	5682.60	
Moisture (%)	500	1832.25	1102.50	1428.00	11.8
	600	1116.15	1713.60	1832.25	
	700	1491.00	1257.90	1501.50	
Volatile Matter (%)	500	19.33	16.78	15.80	44
	600	17.61	14.08	19.50	
	700	16.09	13.61	18.10	
Carbon (%)	500	93.89	96.65	100.31	84.4
	600	96.33	96.21	97.18	
	700	83.39	93.52	99.30	
Hydrogen (%)	500	3.62	3.97	4.76	5.4
	600	3.11	3.40	4.08	
	700	2.34	2.56	3.07	
Nitrogen (%)	500	1.71	1.54	1.41	1.7
	600	1.29	1.11	1.91	
	700	1.83	1.48	1.44	
Oxygen (%)	500	12.92	1.52	6.43	6.7
	600	7.53	8.48	7.74	
	700	15.55	5.46	9.65	
Sulphur (%)	500	1.26	1.31	0.50	1.8
	600	2.02	2.09	1.44	
	700	1.89	1.97	1.00	

The calorific value of the coal used as fuel varies between 5000-6000 cal/g. The calorific value of Tunçbilek coal is 5062 cal/g (Kemal et. al, 2004). The calorific values of the waste adsorbents resulting from the adsorption process varies between 4500-5500 cal/g **(Table 6)**. The calorific value of adsorbents increases as the pyrolysis temperature increases. This depends on the adsorbed HC content as the pyrolysis temperature increases. Similarly, activated adsorbents have higher calorific values because they adsorb more HC than non-activated adsorbents. Waste adsorbents gave calorific value results very close to coal. Waste AC adsorbents have higher calorific value than coal. Moisture and volatile matter contents of all waste adsorbents are less than coal. this is an advantage in terms of emissions to the atmosphere. In general, the C content of the waste adsorbents decreased as the pyrolysis temperature increased. However, these values are higher than the C content of coal. This situation arises from HC compounds with C numbers between C3 and C10 adsorbents adsorb. Similarly, H and O contents mostly showed values close to coal. In general, waste adsorbents have the potential to be used as an alternative fuel to coal.

Conclusion and Recommendations

- BET results showed that char activation increased the surface area of the char material, which increased the adsorption capacity by up to 40-80%. According to SEM imaging, the activation method for all plastic waste types used in the study brought the structure of the chars close to the AC topography. Activated char obtained from 700°C pyrolysis temperature showed the highest adsorption efficiency.
- The components adsorbed by non-activated chars with the highest efficiency were toluene, octane and octane for pyrolysis temperatures of 500, 600 and 700°C, respectively. In activated chars, toluene, styrene and styrene were adsorbed with the highest efficiency, respectively, for the same pyrolysis temperatures.
- Activated char obtained at 700°C has become the most suitable alternative fuel in terms of calorific value and emissions as a result of combustion.

- A new field of evaluation has been proposed as a gas adsorbent for pyrolysis product char. In this way, an alternative material to other natural and synthetic adsorbents that can be used in gas treatment was developed. In this way, economic gains can be achieved and environmental destruction can be prevented.
- It has been suggested to use waste adsorbents as an alternative fuel to fossil fuels. However, necessary precautions must be taken to discharge the emissions resulting from the combustion of these fuels into the atmosphere.

Thanks and Information Note

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EVALUATION OF DOMESTIC BUILT-IN OVEN COOLING SYSTEMS BY USING CFD ANALYSIS

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ABSTRACT

Domestic built-in ovens are one of the essential household appliances in the market status. With the increasing carbon emissions in last decades, regulations are getting more restrictive on energy consumption of ovens. For ensuring efficient energy consumption strategy in ovens, well management heat source strategy is inevitable. During this process different cooking functions are used, and, on this period, high temperature occurs on oven outer surfaces. In order to assure comfort conditions for the users, oven cooling systems have the critical roles. Cooling system is the result of a ventilation system and oven door working together. Ventilation system comprises of fan and air channel. Oven door have the glasses, metal parts for door assembly on oven cavity and air flow channel apparatus. For better evaluation of oven cooling system by monitoring air flow between glasses using CFD method has the advantage. In this study, an oven cooling system has been investigated by using experimental method and CFD methods. Experimental method is used for the validation of CFD analysis. For better examination, different CFD software packages which ANSYS Fluent and FloEFD are used in this paper for evaluating simulation results in different solution perspectives. In both simulations, system is analysed with the same simplified model by using k-ε turbulence model with the similar mesh numbers so that two software packages are compared. All results are used for detected air flow details inside door glasses and ventilation channel. All experimental and numerical studies are applied in Haier Europe Research and Development Center.

Keywords: Built-In oven, Cooling system, CFD, Ventilation system

Introduction

Recently, regulations of household appliances are getting hard day by day because decrease the carbon footprint, safety rules and sustainable usage of appliances. Domestic ovens are the one of the critical household appliances in the user's homes. As these ovens evolve to meet diverse consumer needs, the efficiency and safety of their ventilation and cooling systems play a pivotal role in ensuring optimal performance and user experience. Ventilation systems in built-in ovens are designed to address the challenges posed by heat and steam generated during the cooking process. Efficient ventilation is crucial not only for maintaining a comfortable kitchen environment but also for preventing the accumulation of unwanted odors and condensation. The effectiveness of these systems relies on intricate designs that balance airflow dynamics, heat dissipation, and extraction capabilities. In parallel, cooling systems within these ovens serve a critical role in preserving internal components and ensuring prolonged appliance lifespan. The integration of advanced cooling technologies is essential to counteract the intense heat generated during cooking cycles. These systems must strike a delicate equilibrium between removing excess heat and maintaining an optimal temperature for safe operation. For obtaining high performance ventilation system, CFD method is the primary method in this study because cost effectiveness, time efficiency, flexibility to parametric studies and access to detailed information.

SanAndres et al. studied for the radial fan simulations by using CFD methods. The goal of the study was the get flow characteristics of the fans [SanAndres et al., 2014]. Fahey et al. studied with oven to visualize air flow distribution of the oven door by using CFD and experimental method [Fahey et al., 2008]. Verboven et al., investigated for heat distribution and air flow distribution by using numerical methods in a oven [Verboven et

al., 2000]. Therdthai et al., studied for the baking process in order to obtain optimum baking condition by using 3D CFD model [Therdthai., 2004]. Results showed that air flow distribution was open to improved. Mistry et al., developped a CFD model to simulate the baking process in the gas ovens [Mistry et. al.,2010]. With the CFD and experimental methods, preheating baking cycle is evaluated.

CFD method is useful to simulate the natural and forced convection in ovens [Ploteau et. al., 2012]. Chhanwal et. al., studied for improve bread-baking index in the electrical heating oven by using CFD techniques [Chhanwal et. al., 2010]. Radiative heat transfer is the main focus of their study. End of the study, they compared 3 different radiation model and obtanied baking index.

In this paper, air flow distribution of oven cooling system has been investigated by using numerical approach. Fort he numerical study, ANSYS Fluent and FloEFD software packages are used. Numerical studies have been validated with the experimenal study.

Materials and Methods

For observing the air flow distribution in oven cooling system, simplified CAD model is used as a reference geometry. Simplifications are mandatory to decreased the mesh load in numerical studies. Oven cooling system is comprised of ventilation system and oven door combination. In the ventilation system there are two channels and one radial fan. Bottom channel is used for air suction process through the door. Top channel is used for hot air evacuation from the system. Simplified CAD model is shown in Figure 1 below. Ventilation system is shown in Fiure 2 below.

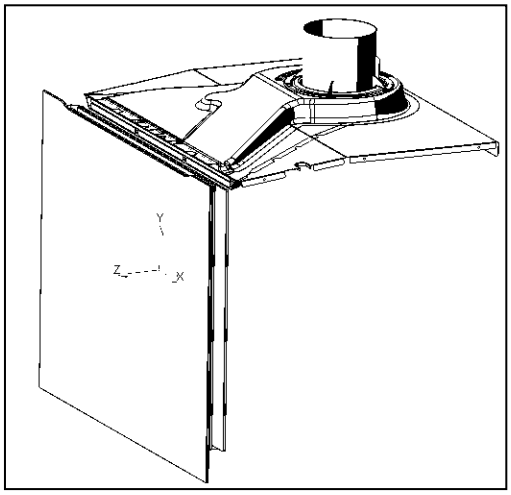

Figure 1. Oven cooling system CAD model

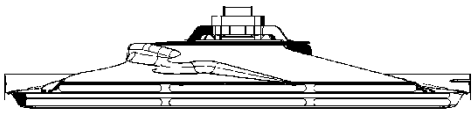

Figure 2. Oven ventilation system CAD model

For modeling the fan working, MRF method is used in both simulation programs. MRF method seperates the domain as a stationary and rotating domains and there are different fan simulation studies used MRF approach in literature [Gullberg & Löfdahl, 2008, Gullberg et. al.,2011]. For governing equations RANS method is used with the finite volume method. As a turbulence solution, $k-\varepsilon$ model is used in both Fluent and FloEFD programs [Yakhot & Orszag, 1986, Lam, 1981, Trebunskikh et. al., 2012]. Governing and $k-\varepsilon$ model equations are shown below.

$$\frac{\partial \rho}{\partial t} + \nabla.\left(\rho \vec{V}\right) = 0 \tag{1}$$

$$\rho \frac{D\vec{V}}{Dt} = \rho \vec{g} - \nabla p + \mu \nabla^2 \vec{V} \tag{2}$$

In Equation 1, ρ is fluid density, t is fluid time, $\vec{V}$ is velocity component respectively. Equation 2 represents the Navier-Stokes equation. Left side of the equilibrium represents product of mass and acceleration. Right side of equilibrium represents sum of the forces effected on fluid. First term of right side is gravity force, second term is pressure gradient and third term is internal extension forces. Equation 3 and 4 shows the turbulence kinetic energy and turbulent dissipation in $k - \varepsilon$ model below [Davidson, 2011, Aktas, 2022].

$$\vec{v}_j \frac{\partial k}{\partial x_j} = P_k - \varepsilon + \frac{\partial}{\partial x_j}\left[\left(\vartheta + \frac{\vartheta_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] \tag{3}$$

$$\vec{v}_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\varepsilon}{k}\left[C_{\varepsilon 1} P_k - C_{\varepsilon 2}\varepsilon\right] + \frac{\partial}{\partial x_j}\left[\left(\vartheta + \frac{\vartheta_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] \tag{4}$$

Coefficients used in Equation 3 and 4 could be specified by experimentally. For the standard $k - \varepsilon$ model values are given Equation 5 below.

$$C_\mu = 0.09, C_{\varepsilon 1} = 1.44, C_{\varepsilon 2} = 1.92, \sigma_k = 1, \sigma_\varepsilon = 1.3 \tag{5}$$

For the mesh strategy, in FloEFD 6.9 million hexahedral mesh, in Fluent 7.1 million polyhedral mesh are used during numerical simulations [Balafas, 2014].

Findings and Discussion

In this investigation, air distribution of oven cooling system has been observed by using CFD method. For the CFD simulations, FloEFD and ANSYS Fluent softwares are used. Simulation results show that both results have similar air velocity on inlet and outlet of ventilation system as shown in Figure 3 and 4. Internal analysis and external analysis are applied in Fluent and FloEFD respectively.

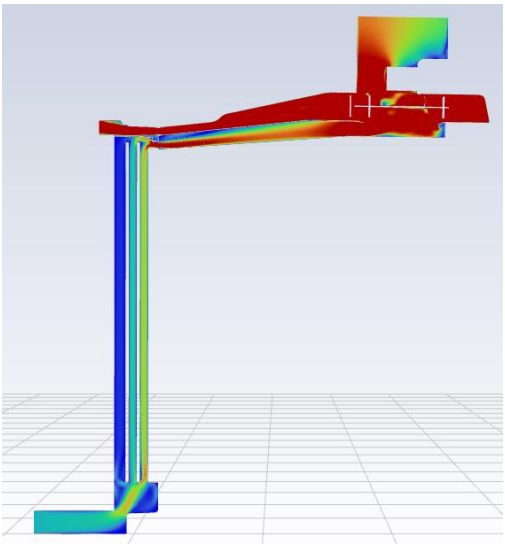

Figure 3. Fluent middle plane velocity contour

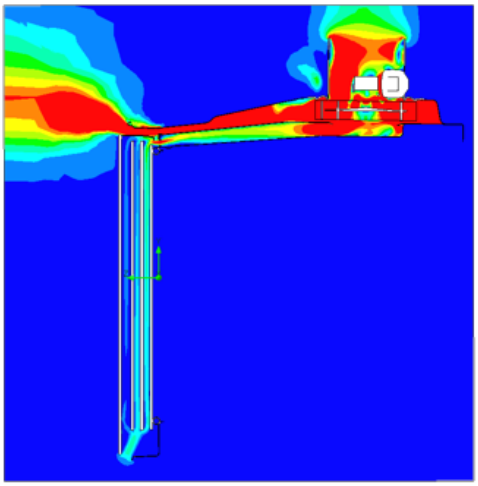

Figure 4. FloEFD middle plane velocity contour

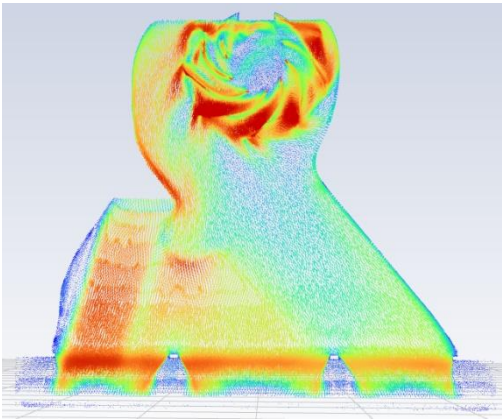

Figure 5. Fluent ventilation outlet velocity

As shown in Figure 3 and 4, middle plane velocity contours are similar in both program. Velocity scale is between 0 – 3 m/s. On Figure 5, outlet velocity distribution is shown from Fluent program. Velocity scale is between 0 – 15 m/s. Results are compared from statistical perspective by using Minitab program. Also, by using experimental method, numerical studies are validated. Results are shown FİgURE 6 and 7 below.

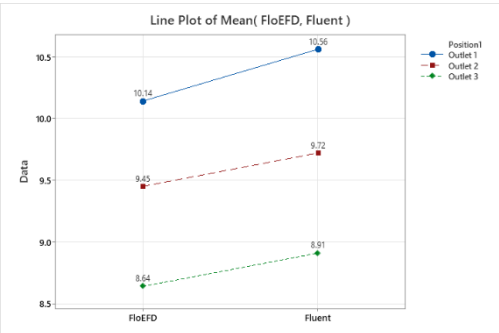

Figure 6. Statistical comparison of outlet velocities

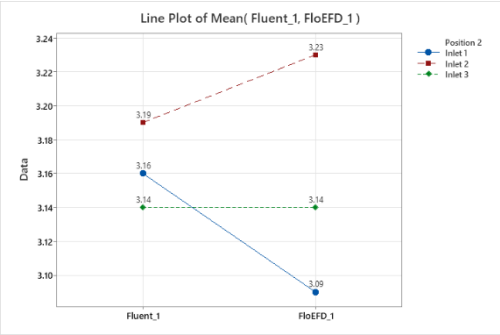

Figure 7. Statistical comparison of inlet velocities

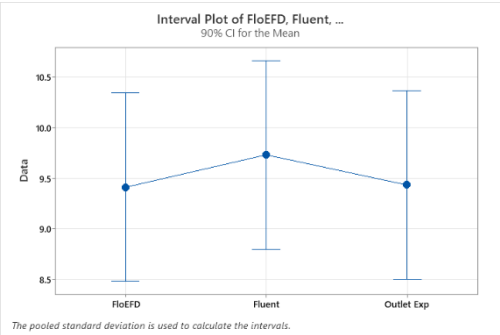

Figure 8. Validation of outlet velocities

In Figure 8 above, validation graph is shown. Results are acceptable from statistical perspective.

Conclusion and Recommendations

In simulation results, similar air flow behaivours have been observed for both program. Air velocity of ventilation inlet and outlet are acceptable as a homogenous air flow for both program. If ventilation outlet results are accepted as a different on Fluent and FloEFD, risk is 65%. If ventilation inlet results are accepted as a different on Fluent and FloEFD, risk is 83%. For both conditions, risk is too high from the engineering perspective. Also, if ventilation results of simulations are accepted as a different from experimental study, risk is 87% which is not acceptable rate.

Thanks and Information Note

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NEW REGENERATIVE BRAKING APPROACH; ROAD TOPOLOGY MODELING

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ABSTRACT

A regenerative braking system is a mechanism that recovers energy by storing the existing kinetic energy of a moving vehicle, which can be used immediately or until needed, and converting it into the same or a different type of energy. Thanks to the regenerative braking system, in addition to reducing the vehicle's fuel consumption, it will use the brake system less, significantly extend its life, and provide a systemic efficiency that can prevent rapid wear of the vehicle's mechanical parts. Today, different regenerative braking methods are used in both internal combustion engine vehicles and electric vehicles. In the work to be carried out, an intersection system will be developed and an inclined road will be constructed to this intersection system. In this way, it was aimed to both slowdown traffic at intersections and reduce unnecessary brake use. In the study, a sample numerical modelling was developed by considering kinetic energy, potential energy and energy conversion formulas. In sample studies, it was observed that the amount of lost braking energy increased as the speed and weight of the vehicles increased.

Keywords: Braking Energy, Regenerative Brake, Regenerative Braking System, Energy Storage

1.INTRODUCTION

Current environmental issues and problems, shortage of fossil energy sources and increment of CO2 emissions make regenerative brake methods more popular, especially in urban areas [1]. To reduce CO2 emissions, changing the use of fossil fuels to alternative zero or low-emission energy sources is a necessity. However regenerative braking is another significant alternative to reduce vehicle emissions [2]. In the literature, the regenerative braking system is defined as a mechanism that converts a vehicle's braking energy into kinetic energy, immediately using the existing kinetic energy or storing it until needed, and recovering energy by converting it to the same or a different type of energy [2-5].

In the transportation field, there is some common regenerative braking methods which are; using electric motors as generator [6-9], rotating flywheel technology [10,11] and hydraulic regenerative braking system [12, 13]. Using electric motors, the battery charging systems recover part of the braking energy and deliver it to the batteries. However, flywheel and hydraulic braking systems feed the stored braking energy back to the transmission system. Although these systems have faster response, they are heavier and larger than those using electric motors. It causes complex mechanical systems, especially in the application of regenerative systems to conventional vehicles.

Using electric motors is the most preferred regenerating method due to its simplicity; since it does not need any extra mechanical devices for energy conversion and storage. On the other hand, this regenerative braking energy cannot be used in some conditions; such as when the battery is fully charged or is not suitable for charging at high voltages [4]. In addition, it is only applicable to some kinds of electric vehicles such as hybrid, fuel-cell or pure electric. Therefore, since the total number of traditional cars are higher than all kind of electric

vehicles, new methods are requested to regenerate braking energy. This study involves modelling a novel and unique Regenerative Braking Slope (RBS) approach to fill this gap.

2. MATERIALS AND METHODS

2.1. Regenerative Braking Slope Method

As it is known, braking is one of the most important factors of energy losses in vehicles. In other words, the deceleration, full stop or stop-start of the vehicle causes a lot of energy consumption and consequently increases CO2 emissions in internal combustion engine vehicles. Environmental conditions such as traffic lights, roundabouts, and traffic signs are the most important traffic elements that require braking because they require vehicles to slow down or stop [14]. For this reason, these traffic elements are taken into account in the modelling of the RBS method.

In the RBS method, a new regenerative braking approach is developed. In the RBS system, braking energy is regained by energy conversion. Unlike the applications on the vehicle as in classical regenerative braking methods, in the RBS method, the kinetic energy due to the speed of the vehicle will be converted into potential energy by going uphill, and during this conversion, the energy will be stored as lost energy and used during downhill acceleration to reduce unnecessary carbon emissions.

Considering a stop sign as shown in Figure 1, by placing the sign higher than the road plane, the energy lost by braking the vehicles is converted into potential energy. As the vehicle travels uphill, its speed (v) slows down. The potential energy stored to reduce the speed of the vehicle is then used to accelerate the vehicle when travelling downhill. With the RBS method, the lost braking energy is regained. Depending on location suitability, the RBS approach can be applied for all traffic elements where a vehicle needs to stop or slow down.

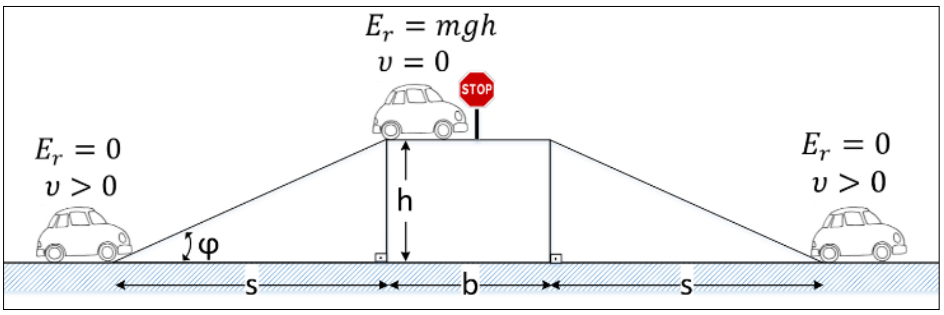


Figure 1. Regenerative Braking Slope Method Modelling

2.2. Calculation Methods

2.2.1. Kinetic Energy

Kinetic energy is the type of energy that an object has due to its motion. Kinetic energy can be expressed as the work spent to accelerate an immobile and massive object to a certain speed. Kinetic energy, which is also obtained by acceleration, remains constant depending on the velocity of the body [15].

Kinetic energy formula of a non-rotating body with speed V and mass m;

$$E_{\text{Kinetic Energy}} = \tfrac{1}{2} \cdot m \cdot v^2 \text{ (J)} \tag{2.1}$$

2.2.2. Potential Energy

Potential energy is the type of energy that an object has due to its height. The potential energy of an object varies depending on its weight, gravitational acceleration and height [16].

$$E_{\text{Potansiyel Enerji}} = m \cdot g \cdot h \text{ (J)} \tag{2.2}$$

2.2.3. Conservation of Energy

The law of conservation of energy explains that energy is constant in the universe, new energy cannot be created from nothing and existing energy cannot be destroyed [17].

In the sample studies, the kinetic energy of the vehicles will be converted into potential energy by utilizing the law of conservation of energy. The calculation of the amount of energy lost during this conversion is given in equation 2.3.

$$E_k = E_{Kinetic\ Energy} - E_{Potential\ Energy}\ (J) \tag{2.3}$$

2.3. Case Studies

Since the RBS method is modelled using kinetic energy and potential energy, the study was carried out for two different cases in order to examine the performance depending on height, instantaneous speed and mass by considering different parameters for the vehicles. Table 1 shows the fixed parameters used during the calculations. These parameters are the mass of 3 different vehicle types, speed values to be applied to all vehicles and gravitational acceleration values. The speed values given are the default speeds accepted for the sample.

Table 1. Fixed Parameters for Different Cases

Parameter	*Value*	*Unit*	*Explanation*
$m_{motorbike}$	120	kg	Motorbike Mass
m_{car}	1400	kg	Car Mass
m_{truck}	25000	kg	Truck Mass
v_1	40	km/h	Speed
v_2	50	km/h	Speed
v_3	70	km/h	Speed
g	9,81	m/s^2	Gravitational Acceleration

2.3.1. Case-1

In Case-1, the amounts of lost braking energy with RBS (Figure 2.1.) and RBS-free (Figure 2.2.) are calculated for 3 different vehicle types: truck, car and motorbike. In this case, the height of the RBS system is assumed to be 4 meters.

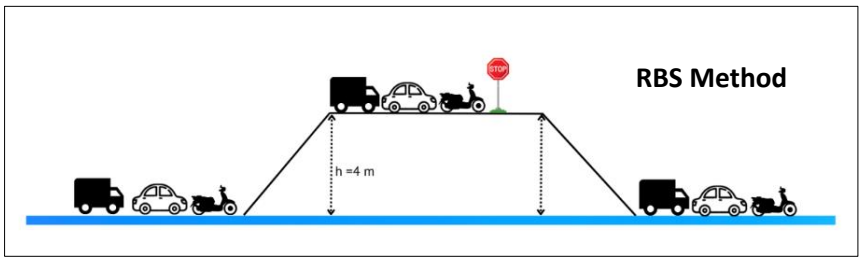


Figure 2.1. Case-1 Method Modelling with RBS

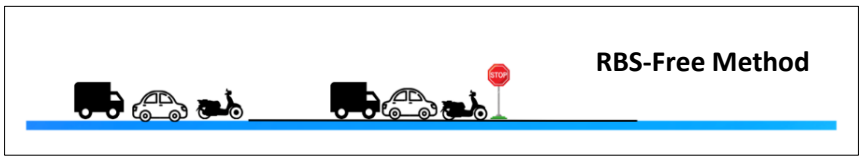
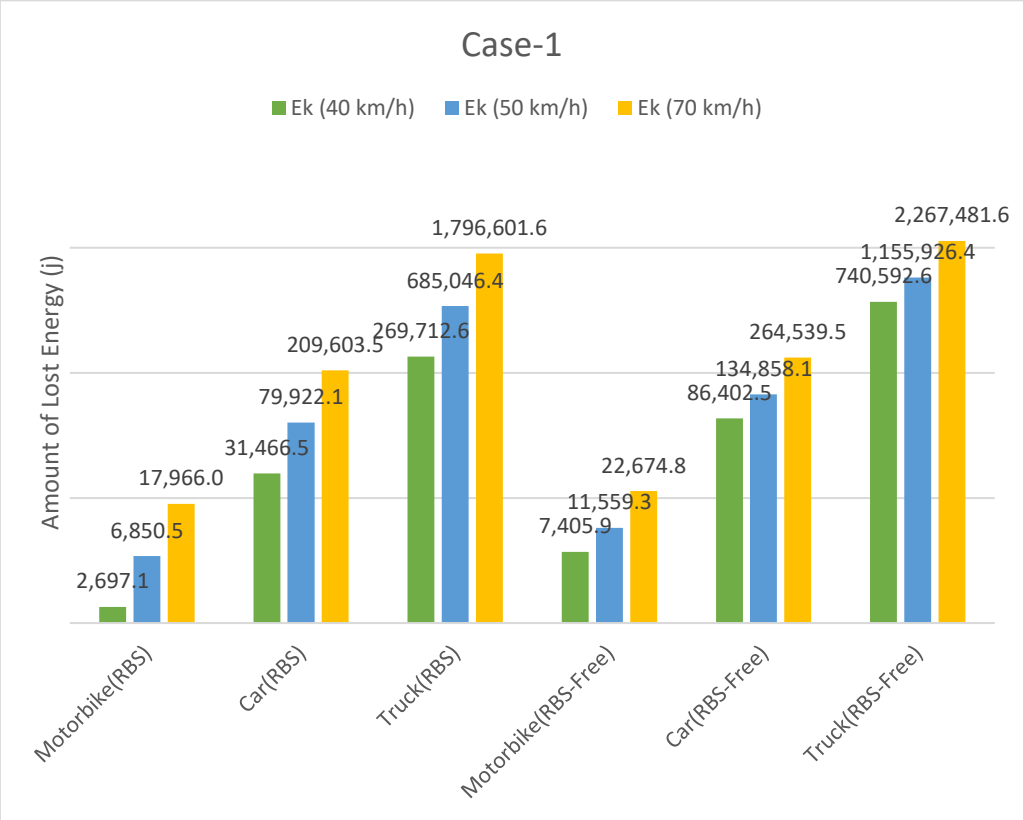


Figure 2.2. Case-1 Method Modelling with RBS-Free

As seen in Graph-1, it is seen that the heavier truck can store much more braking energy than the lighter engine and car in both RBS and RBS-free methods. In addition, regardless of the vehicle type, the amount of energy lost increases as the speed increases. Thus, the stored braking energy also increases. When the method without RBS is compared with the method with RBS, it is seen that the amount of energy lost in the method with RBS decreases.

Graph 1. Comparison of Energy Losses of the Method with RBS and the Method with RBS-Free for Case-1 according to Speeds



2.3.2. Case-2

In Case-2, the height value was given as 2.5 meters for the 3 different vehicle types specified in Case-1, keeping the vehicle weights and speeds the same. All transformation operations performed for Case-1 were also performed in Case-2. Since the amount of slope is less in Case-2 compared to Case-1, it is seen that the amount of energy gained is higher.

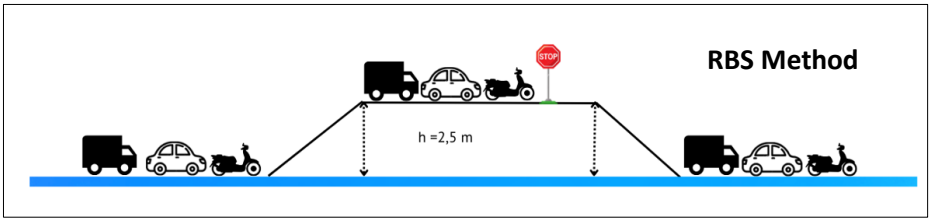


Figure 2.3. Case-2 Method Modelling with RBS

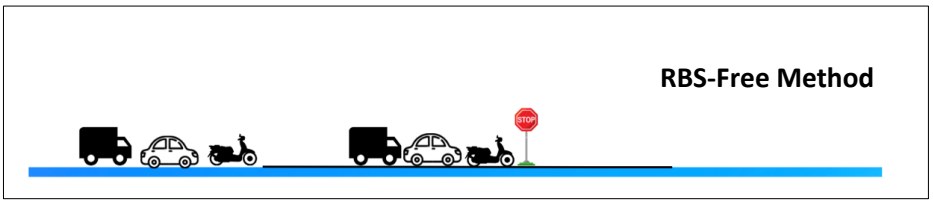
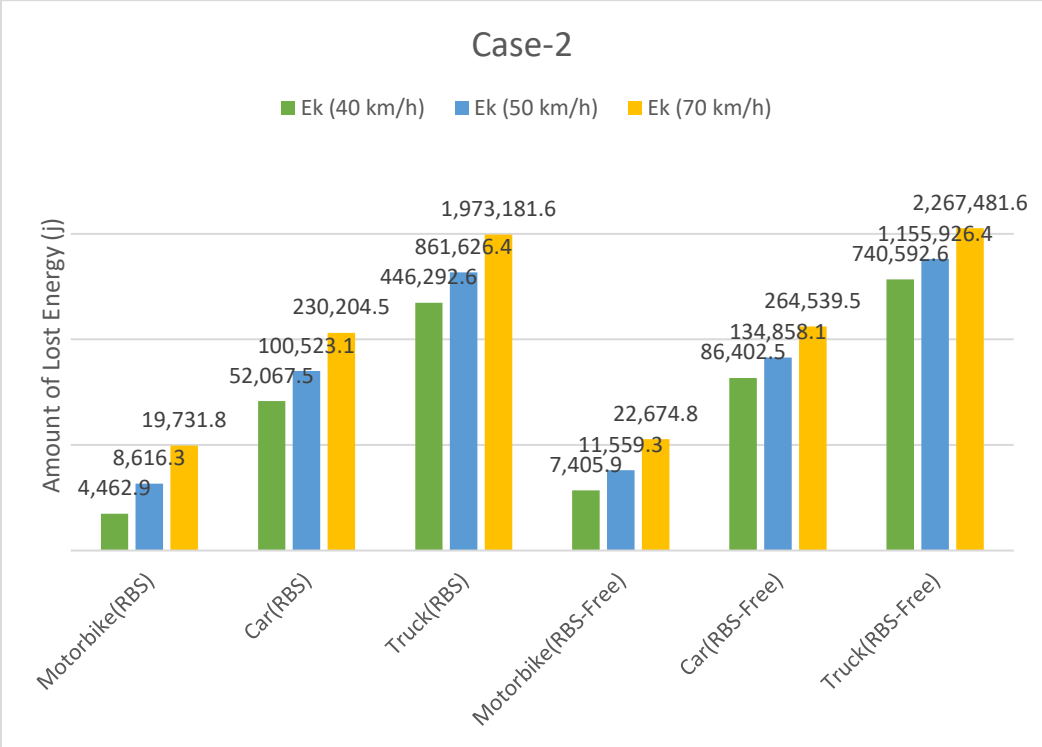


Figure 2.4. Case-2 Method Modelling with RBS-Free

Graph 2. Comparison of Energy Losses of the Method with RBS and the Method with RBS-Free for Case-2 according to Speeds



3. CONCLUSIONS

As can be understood from this study, it is seen that a new approach to regenerative braking methods has been introduced without any modification on vehicles. With this study, the applicability of the regenerative braking slope method in different vehicle types has been observed. At the same time, this study has observed that each vehicle type, regardless of vehicle type, has braking energy gains depending on its weight, speed and position height.

Although this study develops a new approach to regenerative braking methods, in reality, its application can bring serious costs. Instead of applying it to existing roads, it may be easier to apply it to new road construction works and new settlements. In future studies to be developed under the leadership of this study, it is foreseen that road topology optimization studies can be carried out to reduce fuel consumption in vehicles.

4. ACKNOWLEDGEMENT

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HYBRID VERTICAL WIND TURBINE DESIGN

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ABSTRACT

The importance of the energy needed in the modern world is an undeniable fact. It is necessary to have safe, high quality and continuous access to this needed energy. Unlike fossil fuels, wind energy is a more environmentally friendly type of energy. Wind energy, which is among the renewable energy sources, has gained importance and developed in recent years. Until now, wind energy has been active in the field of generating electrical energy in steppe areas, pumping water. Today, it has taken it in the sector as an active energy source. The purpose of wind turbines is to be a system that converts the kinetic energy of the wind into mechanical energy with their blades and then into electrical energy. In this design study, Darrieus and Savonius vertical hybrid wind turbine design was made. The meaning of wind energy, its historical development and the classification of turbines are explained. Darrieus and Savonius designed wind turbines in a hybrid way and tried to achieve the highest efficiency.

Key words: hybrid wind turbine, Darrieus turbine, Savonius türbine and efficiency of hybrid turbine

Introduction

For the hybrid vertical wind turbine design process, two turbine models with the highest efficiency were selected from the literature [Rassoulinejad-Mousavi S M, Jamil M, Layeghi M, 2013]. Turbines consist of two separate parts: an outer wing and an inner wing. Inner wings are Savonius type, outer wings are Darrieus type. The wings should be light. In addition, it must have a feature that makes it easier to glide on the surface from which the wind is blowing. For this reason, composite materials are commonly used in wind turbines [Mishnaevsky L Jr, Kim B, Helga N P, Justine B, Malcolm M, Bent F S, 2017]. Instead, traditional composites, hybrid composites made using nanotechnology have also begun to be used . A common goal of using composites is to prevent fatigue caused by dynamic and static loads in wind turbines. This fatigue can cause damage to the wings.

The most important criterion for wings is the environmental conditions in which they are manufactured. For this purpose, projects were used in which the wing design was carried out taking into account environmental conditions [Mazarbhuiya H M S M, Biswas A, Sharma K K, 2019]. As a result of the optimization process, after the most suitable models were found, calculations were made of the air power passing through the turbines and the turbine power. At this stage, a shape suitable for the Darrieus wing design is selected from among the

wing profiles. For this reason, according to the results obtained in previous studies, the blades used in wind turbines are NACA profiles [Tanürün H E, Ata İ, Canlı M E, Acır A, 2020].

Aerodynamic Calculation

The fundamental principle in wind turbines is to reduce the speed of the wind passing through the turbine blades, thereby converting a portion of the wind's existing kinetic energy into mechanical energy and subsequently into electrical energy [Karabacak, M., Kılıç, F., Cantaş, 2017]

Drag force

The drag force is a force that occurs on a body in the direction of the flow. It represents the force encountered by an object in a random region in the direction of the wind. The drag coefficient, on the other hand, is a dimensionless number used in place of various parameters. It signifies the resistance characteristics of the object and is calculated as shown in Equation-1. [Şentürk, U., Özdamar, A. 2018- Çengel, Y.A., Cimbala, J.M 2012].

$$C_d = \frac{F_D}{\left(\frac{1}{2}.A_p.\rho.V_r^2\right)}$$

The tip-speed ratio for a vertical-axis wind turbine rotating at an angular velocity ω (in rad/s) with a radius r (in meters) is defined as the ratio of the blade tip speed to the free stream wind speed, Vs (in m/s), as in the following formula:

$$\lambda = \frac{r\omega}{V_r} = \frac{2.\pi.r.n}{60.V_r}$$

At low speeds, the turbine blades will rotate slowly, resulting in an inability to efficiently convert the relevant portion of wind power into mechanical energy. Conversely, at high speeds, the turbine will spin rapidly, creating resistance to the wind passing through the blade area.

Reynolds Number

Reynolds number, dependent on the flow regime, dynamic viscosity μ (1.789x10^-5 kg.m/s), air velocity Vs, air density ρ, and turbine length scale Dh = 2r can be expressed as follows.

$$Re_D = \frac{\rho.V_r.D_h}{\mu}$$

Electrical Power

Electrical power, expressed as the power carried by an electrical circuit, is the product of the voltage V across the poles and the current I flowing through it.

$$P = V.I$$

Power coefficient

The power coefficient is a parameter that determines the turbine's input power. The value of the power coefficient is determined by the velocity ratio. If the velocity is maintained at an optimum level, according to Betz's theorem, the blade power coefficient can reach a maximum value of 0.5926. However, due to less-than-ideal real-world conditions, this value typically ranges between 0.45 and 0.55 [Sert Ş. M., 2019].

Wind power increases proportionally with the area of the rotor and the cube of the wind speed. The formula providing maximum energy is as follows.

$$P_{max} = \frac{8}{27}.\rho.A_s.V_r^3$$

The wind wheel can benefit from a certain part of this energy.

$$P_r = \frac{1}{2}.\rho.A_s.V_r^3$$

From here, $\frac{P_{max}}{P_r} = \frac{16}{27} = 0{,}5926$ Betz limit founded.[10]

C_p power coefficient, P_e the useful power generated by the wind türbine, P_r air speed the following relation is provided

$$C_p = \frac{P_e}{P_r}$$

Methodology

The designs of Darrieus and Savonius wings were produced on a 3D printer. The purpose of the experiment is to obtain and compare the volts, amperes, power, and rpm values of Savonius and hybrid wind turbines inserted into the air tunnel at different speeds.

After researching various literary materials, the suitable wing design for the Savonius was selected. The blade in the Savonius wind turbine has a radius of 8.1 cm and a height of 35.6 cm. The blades are crescent shaped with a thickness of 3 mm.

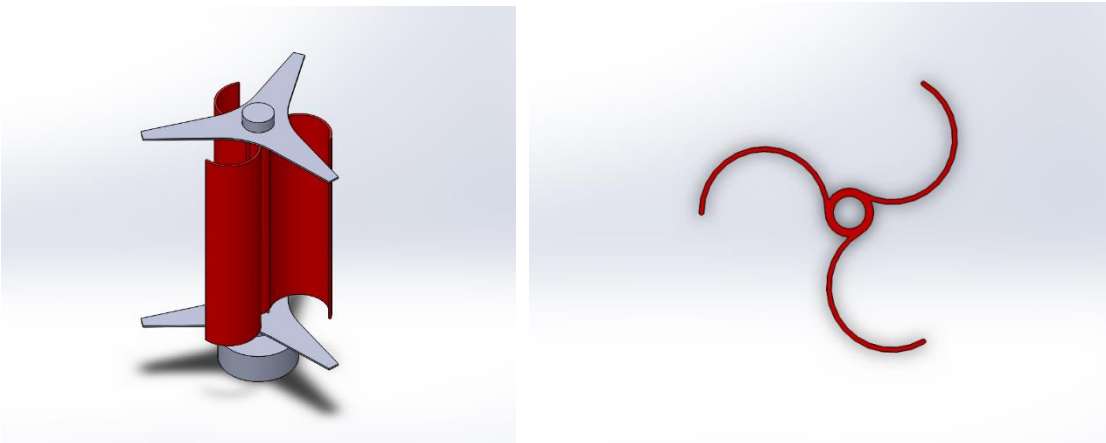

Figure 2. (a) Wind turbine with wings Savonius type (b) view from above

For Darrieus NACA profile 0018 was selected from the four-digit series section family suitable for design. This is because the NACA 0018 blade model provides convenience for vertical turbines in terms of aerodynamic performance.

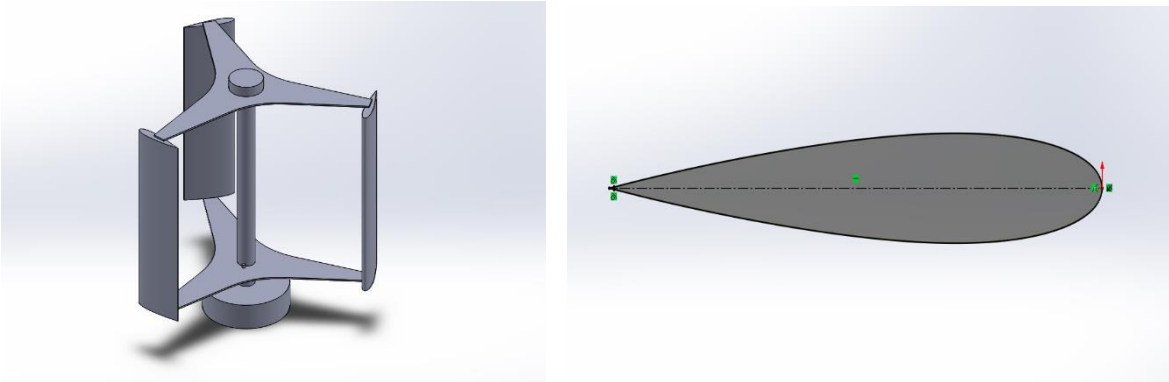

Figure 3 (a) Wind turbine with wings Darrieus type (b) NACA profile 0018

For the research we used a wind tunnel. Thanks to the fins in the air tunnel, it was possible to regulate the speed and conduct experiments at different speeds.

Figure 4. Special wind tunnel with fins for speed regulator

The assembled hybrid wind turbine model was put into the wind tunnel at different speeds and these speeds were measured with an anemometer. These speeds were measured as 19.5 m/s, 21.8 m/s, 22.5 m/s, 23.7 m/s and 24.7 m/s. One of the anemometer measurements made is shown below.

Figure 5. Anemometer and the hybrid and Savonius turbines**.**

For the other experiment, the Savonius model, it was assembled and tested in the same way at different speeds in the wind tunnel. These speeds are 19.3 m/s, 20.6 m/s, 22.3 m/s, 23.8 m/s, 25.5 m/s, 28.8 m/s and 29.2 m/s. It was measured an anemometer. One of the anemometer measurements made is shown below. The

measurement values for the anemometer are as follows: If below 20 m/s, it's ±0.2 m/s, and if above 20 m/s, it's ±0.3 m/s. For the

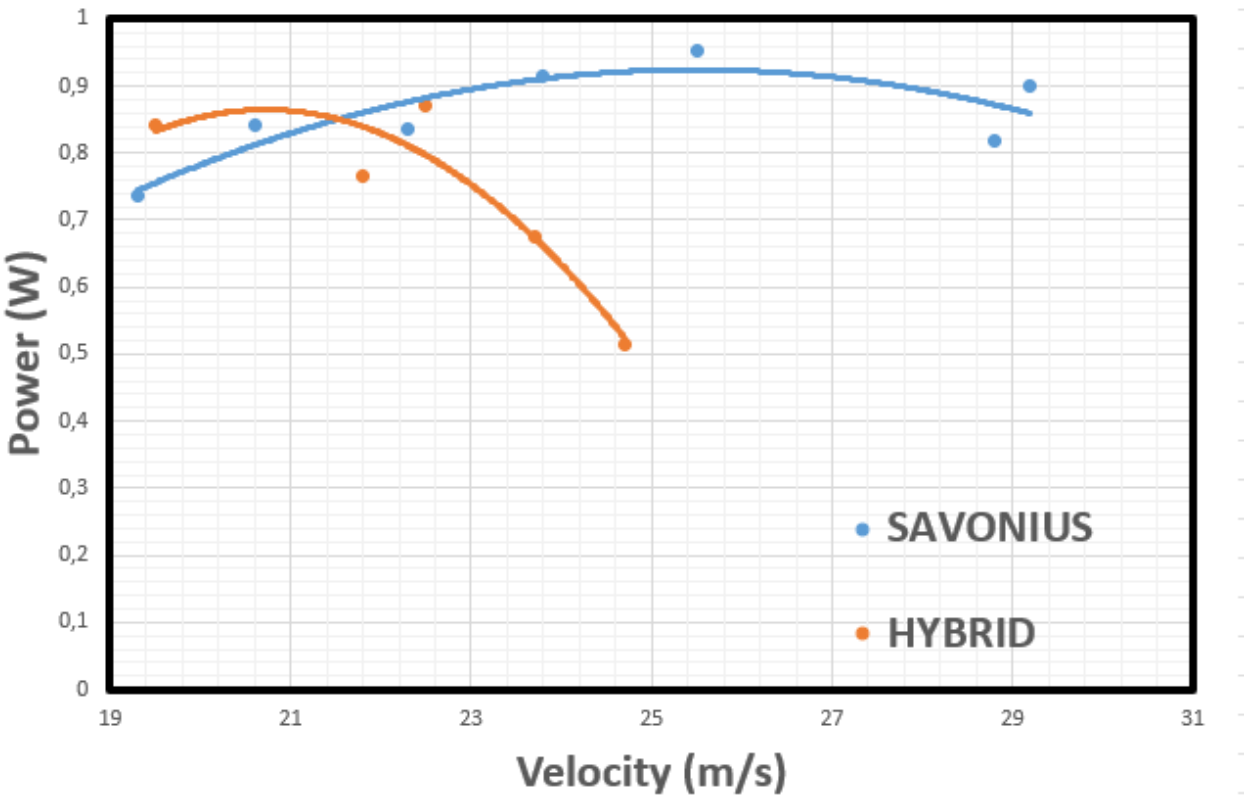

Figure 6. Savonius and Hybrid comparison power-velocity chart

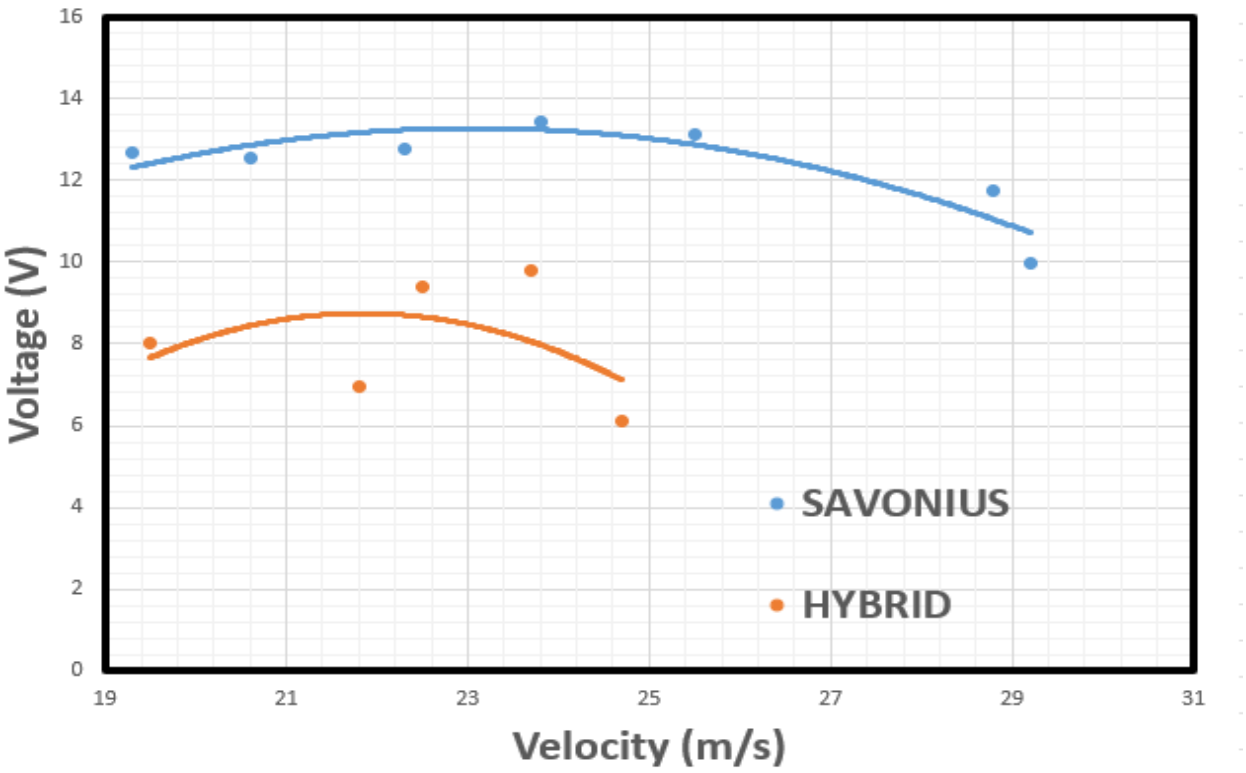

Figure 7. Savonius and Hybrid comparison velocity-volt chart

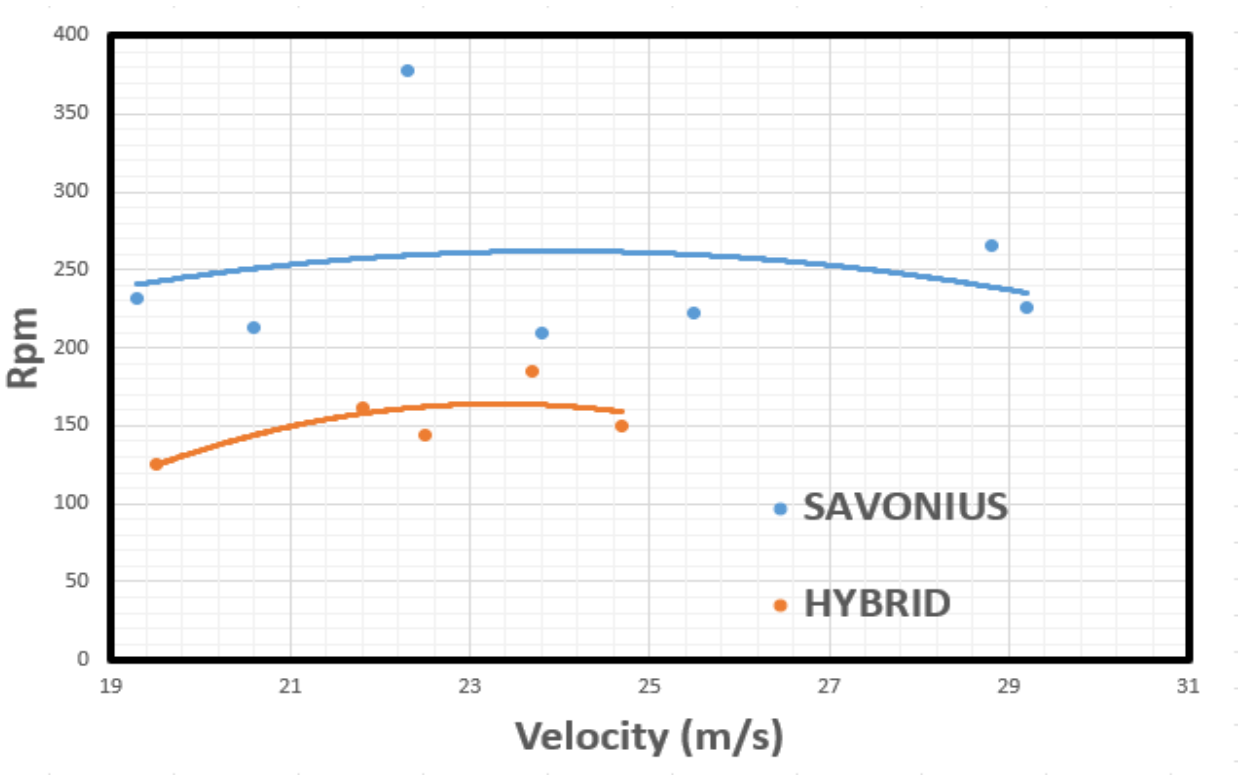

Figure 8. Savonius vs Hybrid rpm- velocity chart

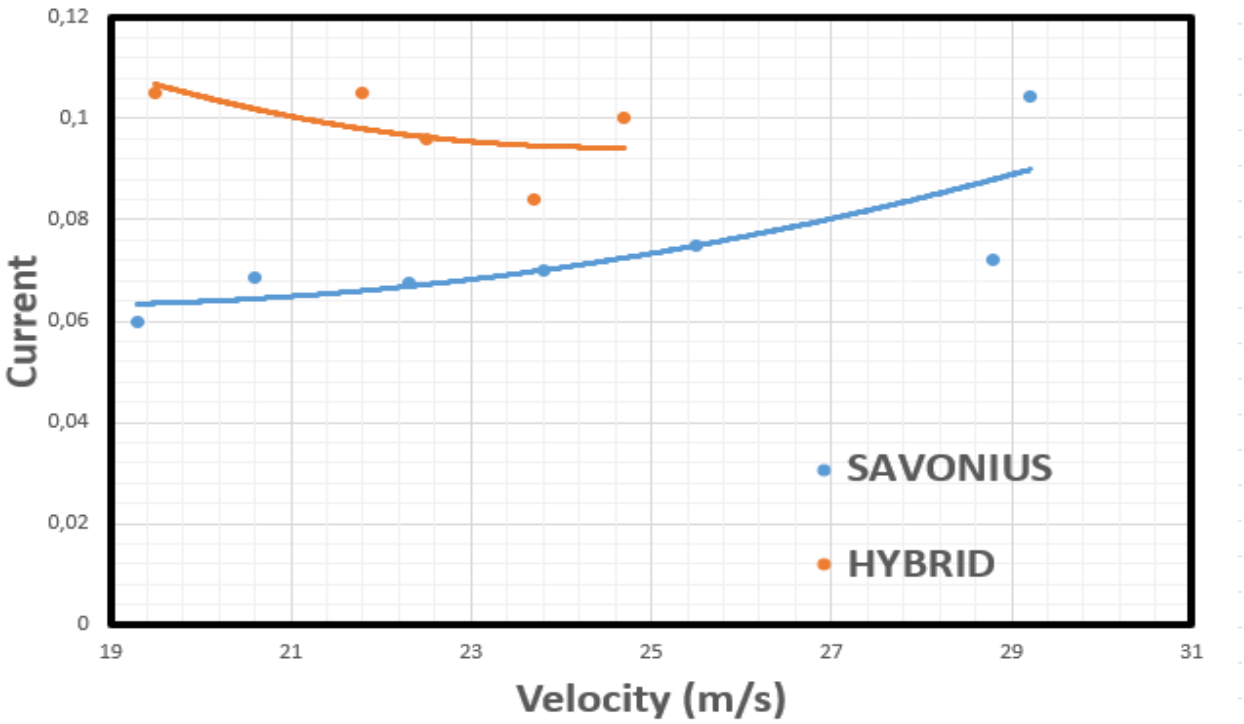

Figure 9. Savonius vs Hybrid current- velocity chart

Uncertainty Analysis

During the experiments, uncertainty will occur in wind and power measurements. The measurement error of the anemometer is ± 3% if it is below 20 m/s, and ± 4% if it is above 20 m/s. voltage, current and power measurement error is ± 0.2%. Total error is ± 3.2%.

Conclusion

In each experiment, data were taken at different speeds. These experiments last for a certain period of time and data flow continues every second. In this section, the average of the data for each experiment was taken and speed-volt, speed-power, speed-ampere and speed-rpm graphs were created. Curves were obtained with these average values created in the two models and were put on the same graph. This situation aims to make it easier to compare Savonius and hybrid models.

As it is seen from Figures 6, 7, 8 and 9 hybrid turbine model is more efficient in the lower wind speeds, while each of Darrius or Savonius vertical turbines more efficient in there faster wind speeds. The reason of this can be explained by the screening effect of two kind of turbines in the fast wind cases. This is in coincidence with literature.

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DIELECTRIC AND PIEZOELECTRIC PROPERTIES OF BNT-BKT CERAMICS PREPARED BY SOLUTION COATING METHOD

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ABSTRACT

In this study, production and electrical characterization of BNT-BKT ($Bi_{0.5}Na_{0.5}TiO_3$-$Bi_{0.5}K_{0.5}TiO_3$) piezoelectric ceramics were carried out. These compositions can be utilized in energy-storage and energy-harvesting applications. Ceramic powders with a composition of 90BNT-10BKT were synthesized by a method called "solution coating". In this method, sodium- and potassium-precursor solutions were coated onto TiO_2 particles. Single-phase perovskite BNT-BKT powders with an average particle size of less than 100 nm were obtained after a one-step calcination process at 700 °C. Ceramic samples prepared using these powders were sintered by conventional sintering at 1150 °C for 2 hours. Composition, phase content, and microstructure analyses of powder batches and sintered samples were carried out using X-ray diffraction (XRD) and scanning electron microscopy (SEM). Dielectric and piezoelectric properties were examined using an LCR-meter. It was determined that the dielectric constant (ε_r), which is an important parameter in terms of storing electric charge, is around 975. The planar electromechanical coupling factor (k_p), which reveals the efficiency of the conversion between electrical energy and mechanical energy of the material for energy-harvesting applications, has a value of 0.28. Experimental results proved that the conventional calcination (850 °C) and sintering (>1200 °C) temperatures of BNT-BKT piezoelectric ceramics can be reduced using the solution coating method.

Keywords: Piezoelectric, Dielectric, BNT-BKT, Energy Harvesting, Energy Storage.

Introduction

Piezoelectric materials convert mechanical energy into electrical charge (direct effect) and the applied electric field into mechanical effect (inverse effect). In another sense, they can transform mechanical energy to electrical energy and vice versa. In this way, they find use in applications such as electrical energy-storage, mechanical energy-harvesting, and electromechanical sensors. The most preferred materials in such applications are lead-containing piezoelectrics such as lead zirconate titanate (PZT, $Pb(Zr,Ti)O_3$). However, the lead content of these compositions, around 60% by weight, is seriously harmful to both human health and the environment. Hence, the development of lead-free alternative piezoelectric compositions has recently gained importance.

BNT (bismuth sodium titanate)-based compositions, among the lead-free piezoelectric materials, gained much attention due to their high piezoelectric constant and strain values [Takenaka & Nagata, 2005; Leontsev & Eitel, 2010]. However, pure BNT is hard to pole due to its large coercive field and high conductivity. Solid solutions between BNT and BKT(bismuth potassium niobate) exhibit a phase diagram similar to that of PZT system [Quan et al., 2014]. In addition, they can easily be poled. Electrical properties of BNT-BKT systems can be improved using compositional modifications [Kainz et al., 2014], doping [Kalem, 2016], and composite design [Bai et al., 2018]. But, Bi, Na, and K are volatile especially at high temperature sintering (>1200 °C) of BNT-BKT ceramics. As a result, the initial stoichiometry deteriorates after sintering. Besides, undesired pyrochlore phases ($K_4Ti_3O_8$, $K_2Ti_6O_{13}$, $NaBiTi_6O_{14}$) can be formed due to the nonstoichiometry and worsen the electrical properties [Kainz et al., 2014].

Formation of pyrochlore phases between lead and niobium ($Pb_5Nb_4O_5$, $Pb_3Nb_2O_8$, and $Pb_3Nb_4O_{13}$) was also encountered in PMN-PT (lead magnesium niobate – lead titanate) systems during production. Colloidal coating technique, a solution-based synthesis method, has been successfully applied in PMN-PT system to inhibit the formation of mentioned phases [Gu et al., 2005; Luo et al., 2007]. Moreover, this method allows the production of nanometer-sized powders. Ceramics with high density can be obtained since atomic diffusion between these particles occur faster during sintering. Conventional sintering temperature (≥1250 °C) for KNN composition (potassium sodium niobate) reduced to 1100 °C via the coating method [Li et al., 2009]. In another study, $BaTiO_3$ nano-powders were obtained by coating TiO_2 on $BaCO_3$. Calcination temperature decreased from ≥800 °C to 600-650 °C [Buscaglia et al., 2007]. To prevent the formation of pyrochlore phases in BNT-BKT compositions, different studies based on sol-gel [X. Chen et al., 2010], hydrothermal [Kanie et al. 2011], and stearic acid gel [Li et al., 2011] methods were conducted. However, sintering of bulk samples using these powders yielded low density and low piezoelectric properties. In this work, solution coating method was employed to prepre 90BNT-10BKT powder. Synthesized powders were used to produce ceramic samples by conventional sintering. The focus was to investigate the effect of powder synthesis method on the dielectric and piezoelectric properties of the sintered samples.

Materials and Methods

Production of 90BNT-10BKT powder was achieved in two steps. In the first step, solution coating was performed by coating the sodium (Na) and potassium (K) containing precursor solution on sol-gel derived TiO_2 particles (anatase, D50 ≅ 33 nm). In the second step, the coated particles were added to a Bi-containing precursor solution and a slurry was formed. The slurry was then dried and calcined to obtain the final crystalline powder. Sol-gel synthesis of TiO_2 particles and the steps of the coating process were described elsewhere [Kalem and Şavklıyıldız, 2023]. Precursors and solvents used during the above-mentioned production steps were Sodium hydroxide and Potassium hydroxide in solid pellet form (≥%98, Sigma-Aldrich), Bismuth(III) nitrate pentahydrate (%98, Sigma-Aldrich), Ultra-purified (distilled) water (Resistivity>18,2 MΩ.cm), and Nitric acid (0.1 N, Norateks Chem.). 0.9 g Na-precursor, 0.14 g K-precursor, 4 g TiO_2 powder, and 12.13 g Bi-precursor were used to produce the 90BNT-10BKT composition. Thermal analysis (DSC-TG, Setaram Labsys Evo) was performed to determine the calcination temperature of base BNT powder prepared by the coating process. For analysis, 25 mg of powder was heated from room temperature to 1100 °C at a rate of 10 °C/min.

Green ceramic discs, each measuring 13 mm in diameter and 1 mm in thickness, were prepared using the calcined powder plasticized by 2% PVA (polyvinyl alcohol) addition. The discs were compacted by uniaxial pressing under a load of 200 MPa. Dilatometry analysis (Misura 3 ODHT) was performed to determine the sintering temperature of the samples. For the measurements, disc samples were heated from room temperature to 1200 °C using 10 °C/min heating rate. Maximum shrinkage value was obtained at around 1100 °C. Based on this result, for full densification to be achieved, samples were sintered at 1150 °C for 2 h. All heating and cooling rates during sintering were maintained as 4 °C/min.

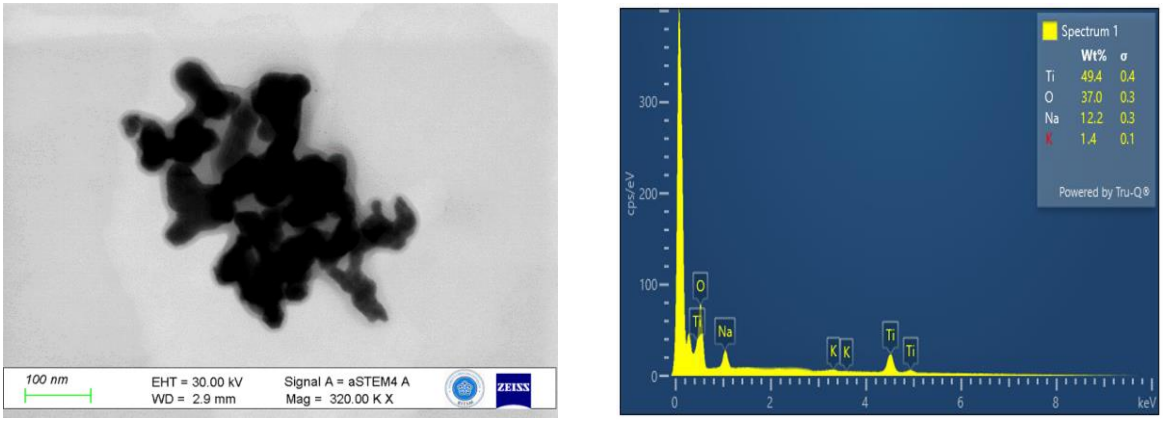
Crystalline structure and phase content of the samples were determined using X-Ray Diffraction technique (XRD, GNR Europe). Measurements were performed using Cu-Kα (λ=0,154 nm) radiation with 2θ range of 20°-80°, 2°/min scanning rate, and 0,017° step size. Microstructure of powder batches were investigated using a Field Emission – Scanning Electron Microscope (FE-SEM, ZEISS GeminiSEM 500). Energy dispersive X-ray spectroscopy (EDS) unit of FE-SEM was used to determine the elemental composition of the powders. Prior to FE-SEM analysis, surface of powder samples was coated with Ir (Iridium) via magnetron sputtering. To get an image from particles having an average size of ≤50 nm, Scanning Transmission Electron Microscopy (STEM) mode of FE-SEM equipment was used. For the STEM study, 0.01 g of powder was dispersed in 20 ml ethanol absolute and ultrasonicated for 10 min. 3-4 droplets from this dispersion was dropped on a 200-mesh grid.

For the measurement of dielectric and piezoelectric parameters, diameter and thickness of the sintered samples were measured and the sample surfaces were electroded with silver paste. The surface was metalized by firing the paste at 700 °C for 30 min. Electrical properties were measured using an LCR-meter (Hioki).

Findings and Discussion

In order to check the coating process, 1 ml sample suspension was taken from the Na and K precursor containing aqueous solution in which TiO_2 nanoparticles were suspended. This sample was added to 100 ml distilled water to obtain a diluted solution. A few droplets were taken from the diluted solution and investigated at STEM mode of FE-SEM (Figure 1(a)). There is a ring-shaped coating surrounding the particles. While the ring surrounding the particles appear light-colored, TiO_2 particles seem darker. It is possible that Na^+ and K^+ ions in the precursor solution, attracted to the surface of TiO_2 nanoparticles, can precipitate as components such as NaOH and KOH; similarly reported in some studies in literature [Li et al., 2009; Gu et al., 2003].

Elemental spectrum of the coated particles, given in Figure 1(b), proves the existence of Na and K surrounding the TiO_2 particles. Theoretical elemental composition of the 90BNT-10BKT composition was calculated as 52% Ti, 34.7% O, 11.2% Na, and 2.1% K. The values obtained via EDS analysis are close to the calculated values.



(a) (b)

Figure 1. (a) STEM image of TiO_2 nanoparticles obtained after the coating process, (b) Elemental spectrum obtained by general area EDS scanning of the particles in (a).

Figure 2 shows thermal analysis (DSC-TG) curves of the base BNT powder. The thermal degradation process occurred in 3 stage and the total reduction in weight is 8.894%. There is no significant change in weight and heat flow above 630 and 700 °C, respectively. Therefore, it can be concluded that BNT crystallization was completed at 700 °C. According to this result, a calcination process around 700 °C would be sufficient to obtain the perovskite phase. Endothermic and exothermic peaks in the heat flow curve were caused by the removal of physical water, residual solvents, volatile organics, and the formation of the perovskite BNT phase [Cernea et al., 2010; Kim et al., 2003; Zubair et al., 2021]. Based on the thermal analysis data, 90BNT-10BKT powder was calcined by heating to 700 °C with a rate of 5 °C/min and soaked for 3 h at this temperature in a muffle furnace (Protherm PLF 140).

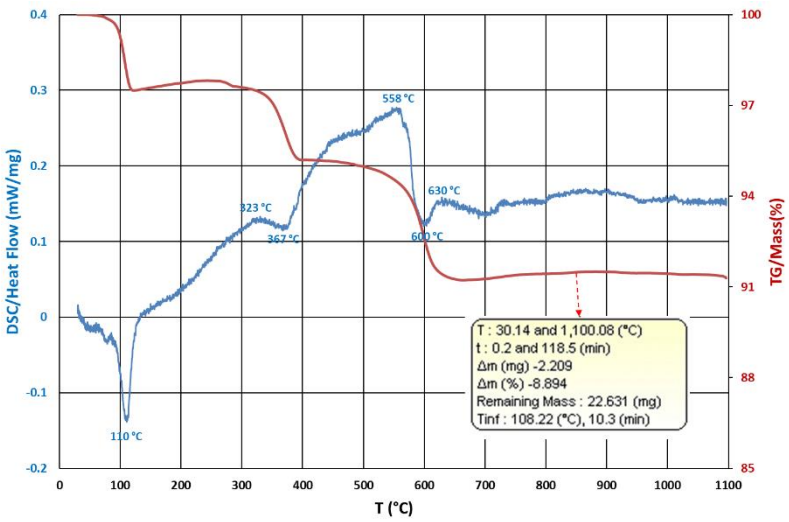


Figure 2. DSC-TG curves of dried BNT powder obtained by the coating method.

Microstructure images of calcined BNT-BKT powder are given in Figure 3. Images of both the powder batch (Figure 3(a)) and the particles (Figure 3(b)) demonstrate a powder consisting of mostly equiaxed particles. Average size obtained via Figure 3 is ≤100 nm. In addition, an average particle diameter of 63.76 nm was obtained via size distribution measurement in DLS equipment. This diameter value is coinciding with the values obtained from FE-SEM data in Figure 3a.

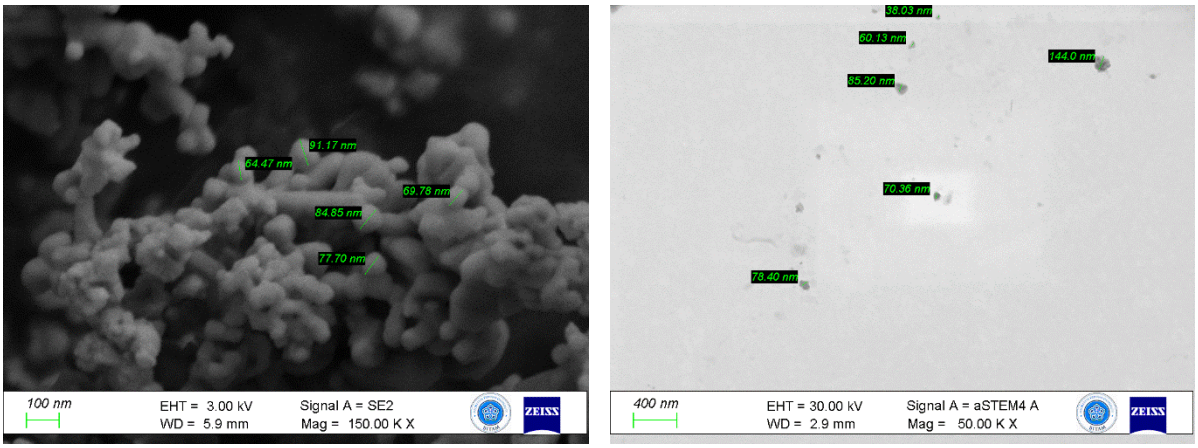


Figure 3. (a) FE-SEM image of calcined 90BNT-10BKT powder batch, (b) STEM image of calcined 90BNT-10BKT particles.

Figure 4 shows the XRD pattern of 90BNT-10BKT sample sintered at 1150 °C. The pattern proves that the pure perovskite structure was achieved. 2θ values of all the peaks belong to $(Bi_{0.5}Na_{0.5})TiO_3$ (JCPDS no: 01-089-3109) and no secondary or pyrochlore phase peaks were detected.

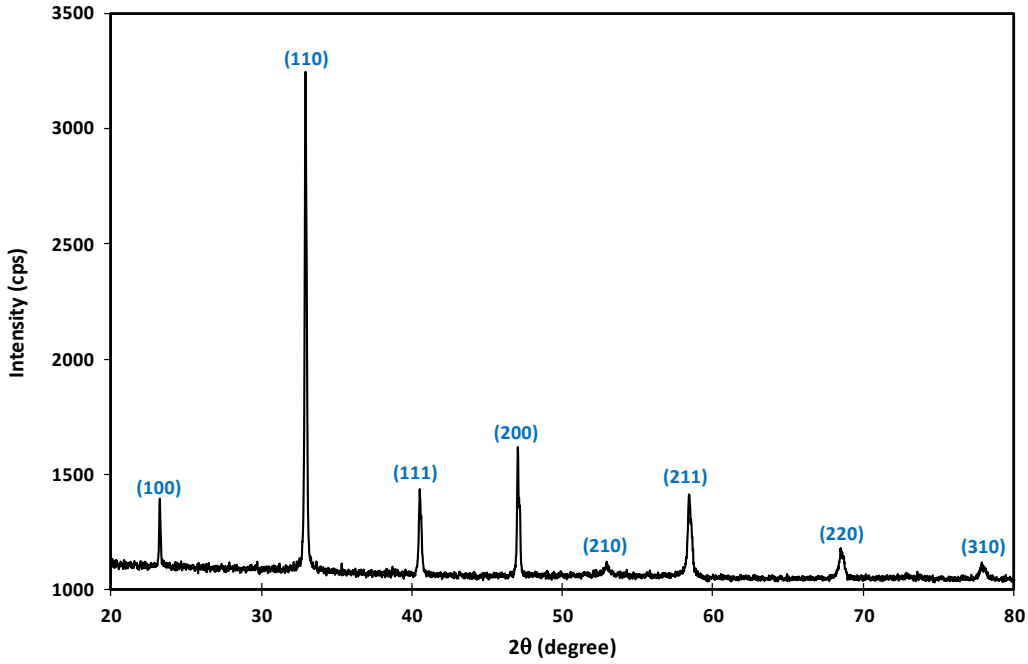


Figure 4. XRD pattern of 90BNT-10BKT sample sintered at 1150 °C.

Dielectric constant (ε_r) and planar electromechanical coupling factor (k_p) of ceramics with 90BNT-10BKT composition prepared via coating process were measured as 975 and 0.28, respectively. On the other hand, similar compositions produced by conventional mixed-oxide method exhibited K=960 and k_p=0.26. There was a slight improvement in the dielectric and piezoelectric parameters, but this improvement was achieved through lower calcination and sintering temperatures.

Conclusion and Recommendations

We showed that pyrochlore-free perovskite powders with a composition of 90BNT-10BKT could be synthesized with a single calcination step using a solution coating approach. The coating of TiO_2 particles in a Na&K-precursor solution physically separated Bi_2O_3 from TiO_2, which thereby prevented the formation of the pyrochlore phase. Conventional calcination temperature of ~850 °C for BNT-BKT ceramics could be reduced to 700 °C. In addition, conventional sintering temperature of >1200 °C could be decreased to 1100 °C, owing to the enhanced atomic diffusion rate between nanometer sized BNT-BKT particles. Both the dielectric constant (ε_r) and the electromechanical coupling factor (k_p) values were improved which are crucial for energy conversion in these materials.

Thanks and Information Note

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COMPARISON OF STORAGE TECHNOLOGIES IN POWER SYSTEMS INCLUDING RENEWABLE ENERGY PLANTS

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ABSTRACT

Renewable energy sources cannot provide continuous energy due to their nature. Although power plants such as solar and wind do not have resource costs, operating costs and system stability are affected because the energy is not continuous. Excess energy produced from alternative sources is stored by transferring it to different types of energy storage units, and the stored energy meets the load demand when the primary resources are insufficient (Kozak & Kozak, 2012). The whole world, especially the countries located in the "Sun Belt" (36-42 north and south latitudes), should benefit from the inexhaustible energy source in the most beneficial way (Hakan et al., 2010). The amount of energy used on Earth is 10th thousands of the amount of sunlight reaching the Earth. If humans use only 0.01 of the sunlight coming into the world efficiently, they can meet all their energy needs. Energy storage is the collection and storage of energy in periods when there is excess energy and its use in periods when energy is unavailable. Thanks to energy storage, it minimizes energy outages and increases the security of electrical networks (Aslan et al., 2014). Therefore, better and more efficient storage of renewable energy resources is essential to balance the fluctuations in energy demand, make power resources continuously available, and increase the sustainability of the energy system. To benefit from renewable energy resources more efficiently, many studies have been carried out to store energy on Earth (Emeksiz & Kara, 2022). Energy storage has been attempted for years with different methods and purposes. Within the scope of this study, energy storage methods will be examined, and the best energy storage method will be determined through Matlab/Simulink.

Keywords: Energy storage- super capacitor-batteries.

INTRODUCTION

As the world population increases day by day, the energy demand also increases. To meet the energy demand, renewable energy sources must be used effectively. However, renewable energy sources cannot provide continuous energy due to their nature. Although power plants such as solar and wind do not have resource costs, operating costs, and system stability are affected because the energy is not continuous. Excess energy produced from alternative sources is stored by transferring it to different types of energy storage units, and the stored energy meets the load demand when the main resources are insufficient.

Energy storage is the collection and storage of energy in periods when there is excess energy and its use in periods when energy is not available. Thanks to energy storage, it minimizes

energy outages and increases the security of electrical networks. Therefore, better and more efficient storage of renewable energy resources is very important to balance the fluctuations in energy demand, make power resources continuously available, and increase the sustainability of the energy system. To benefit from renewable energy resources more efficiently, studies on "Hybrid energy storage systems (HESS) and advanced Rechargeable Battery Technologies (ARBT)" have been concentrated around the world (Aslan et al., 2014).

When the systems in the literature are examined, it appears that there are many types of advantageous batteries and Hybrid Energy Storage systems (HESS). Hybridization offers the advantages of hybridized devices and reduces the negative effects of speed changes or high charge/discharge levels in high power density applications (Zabara et al., 2021).

For HESS, battery types must first be selected. There are some criteria we need to consider when determining energy storage systems. These criteria are: energy capacity, efficiency, cost, life and durability, reliability and safety, application flexibility, and charge-discharge rates.

When making calculations on the battery in solar photovoltaic systems, the mass of the battery is calculated by proportioning the gravitational energy density (Egrav) to the battery capacity (C) (Rydh, 2003):

$$Mass\ (M) = \frac{Egrav}{C} \quad (1)$$

Electrical energy input (Ei) throughout the life of the battery is calculated by means of the maximum number of cycles (N) and capacity (C):

$$\text{Electrical Energy Input(Ei)} = C\ x\ 3600\ x\ N \quad (2)$$

In the electricity storage system, the ratio between electrical input and output must be calculated correctly. Completely discharging the battery will cause irreparable damage to the battery. Therefore, the discharge rate is limited to 80% of the battery capacity. For this reason, the discharge factor (D) is 0.8 (Hammond & Hazeldine, 2015).

$$Energy\ Output\,(Eo) = Ei\ x\ D \quad (3)$$

The efficiency of the battery (Zakeri & Syri, 2015):

$$\text{Battery Efficiency } \eta sys = \frac{Eo}{Ei} \quad (4)$$

When the HESS structures on the market and the storage technology inside are examined, lead acid, sodium-sulfur, redox flow, lithium-ion batteries and supercapacitors play an active role.

According to Poullikkas' study, batteries used in electricity storage systems are mainly used to achieve large-scale solar and wind energy integration in the existing power system by ensuring grid stability, frequency regulation, and smoothness of wind and solar energy. Sodium-sulfur batteries are used in large battery systems, while vanadium redox flow batteries are used in small-sized energy storage systems. In the Rubenius project in California (USA), sodium-sulfur batteries were preferred in the solar and wind energy storage power plant. Thus, grid stability, power quality, and frequency regulation are ensured (Poullikkas, 2013). However, sodium-sulfur batteries have some disadvantages. These disadvantages are security issues and high initial costs. Pure sodium is a hazardous material and will burn if it comes into contact with air and moisture. In addition, short circuit and exothermic reactions may cause the battery temperature to rise too high (around 2000 ˚C) (da Silva Lima et al., 2021).Lead acid batteries, which have a wide range of applications, are a preferred battery type in power quality, UPS and rotary reserve applications. Lead acid batteries are important in fixed energy storage systems. Advanced VRLA (valve-regulated lead acid) batteries equipped with carbon-enabled electrodes have a life cycle that is 10 times longer than conventional lead acid batteries. (Poullikkas, 2013).

Lithium-ion batteries (LIB) have a significant market share in energy storage due to their high energy density, high efficiency, long life, and environmental friendliness (da Silva Lima et al., 2021).

Redox Flow batteries: Unlike batteries that use electrodes composed of active material such as lead acid and lithium ion, these systems store a charge of redox pairs dispersed in a fluid (gas or liquid) stored in reservoirs physically isolated from the electrodes. It allows independent scaling of power and capacity by measuring the size of the electrode stack and the volume of the reservoirs. Redox flow batteries appear as an alternative to Lithium-ion batteries because Redox batteries are safer, longer lasting, and well scalable (Rubio-Garcia et al., 2020)

Supercapacitors(SC) are another technology that stores energy in electricity. SCs: It has high efficiency, high power density, and almost unlimited cycle stability. The function of the supercapacitor in hybrid energy storage systems is to provide voltage stabilization, reduce system cost, and increase battery life (Şahin & Blaabjerg, 2020). Deep charge/discharge charging capability is available, but the capital cost ($300-2000 per kWh) is relatively high. Qu and Qiao (Qu & Qiao, 2011) and Abedini and Nasiri (Abedini&Nasiri, 2008) showed that wind energy output will remain constant thanks to the charging and discharging of SCs in wind energy production. Li and his colleagues(Li et al., 2010) designed a hybrid energy storage system consisting of a

vanadium-redox flow battery and supercapacitor. When the simulation results were examined, it was observed that the wind energy output became smoother with the designed hybrid system.

Additionally, hybrid system applications containing supercapacitors have lower battery costs, higher overall efficiency, and longer battery life (Ren et al., 2017). The Electrochemical Impedance Spectroscopy and Differential Evolution optimization algorithm by Zabara and colleagues (Zabara et al., 2021) predicted the current distribution and voltage response of parallel connected hybrid battery/supercapacitor systems with high accuracy. Taking into account the parameters of the supercapacitor (size, cost, etc.), Lithium Iron Phosphate (LFP) and Lithium Vanadium Pentoxide (LVO) batteries were hybridized with supercapacitors ranging from 10 mF to 500 F, and the results obtained were shown through graphs. Lithium-ion or redox flow batteries have low power density and slow charge/discharge rate. Supercapacitors absorb high-frequency power surges and maintain the voltage of the DC link within the appropriate range. SCs do not provide very high power but are used to meet the rapidly increasing energy demand within seconds (Şahin & Blaabjerg, 2020).

Ali and his colleagues (Ali et al., 2022) compared different power management strategies (filtration, rule-based, and fuzzy logic techniques) applied in HESS, and the supercapacitor showed better performance with the fuzzy logic-based technique. The number of cells in SC was reduced, and significant cost savings were achieved. With the combination of Vanadium Redox Flow battery (VRFB) and supercapacitors (SC), high load demand is met, and power fluctuations are eliminated.

Khan and colleagues (Khan et al., 2018) developed a hybrid storage system consisting of a supercapacitor and lithium-ion battery to shorten the charging time of an electric wheelchair. They used a fuzzy logic-based intelligent energy management system (FLIEMS). FLIEMS regulates the power received in Lithium-ion batteries by controlling the bi-directional power flow. A dual active bridge isolated bidirectional DC converter (DAB-IBDC) was used for power conversion. Thus, galvanic isolation and high power conversion efficiency were achieved compared to traditional converters.

Malar and colleagues (Malar et al., 2023) proposed an adaptive strategy for battery energy storage (BES) and power flow management of hybrid renewable energy systems (HRES). From simulations made with MATLAB/Simulink, it has been determined that traditional trial and error-based PI tuning produces high stages. In contrast, the proposed method produces better performance with fewer stages.To maximize the use of renewable energy resources, it is necessary to manage the power flow between the components of hybrid energy systems well. The power management flow chart of the Hybrid energy system prepared by Güven et al. (Güven & Yörükeren, 2022) is shown in Figure 1. Ebatt(t) in the flow chart refers to the usable capacity of the battery at time t (kWh), Ebattmax refers to the maximum capacity of the battery, and Ebattmin refers to the minimum capacity of the battery.

The possible situation seen in Figure 1 is Ebatt(t)<Ebattmax(t). Renewable energy sources (wind, sun, etc.) provide sufficient energy, and batteries charge the excess energy.

In the second case, the energy of renewable energy sources exceeds the load demand. In this case, the system will discharge to waste energy. (Ebatt(t)= Ebattmax(t))

The third situation is that the energy obtained from renewable sources needs to be increased. In this case, the current energy stored in the battery ensures that the load demand is met. (Ebatt(t)>Ebattmin(t))

The last situation is that there is no energy in the battery banks, and renewable energy sources must be increased to meet the load demand. In this case, diesel generators come into play to meet the load demand. The battery bank is charged while the diesel generator is active. The diesel generator is stopped when wind and solar energy sources start producing power again. (Ebatt(t)<Ebattmin(t))

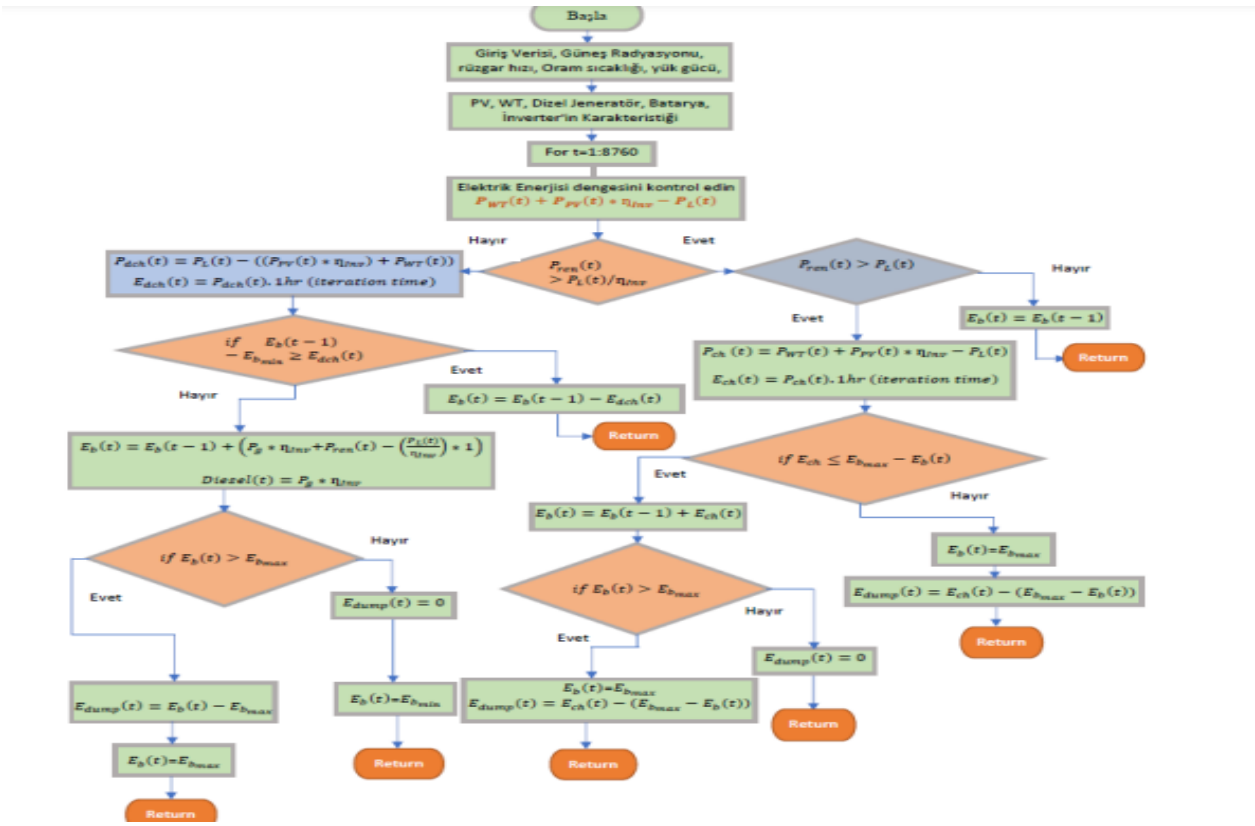

Figure 1. Power management flow chart of hybrid energy system

The management process starts with comparing the load demand with the energy produced by renewable energy sources and is shaped depending on the result. (Güven & Yörükeren, 2022)

MATERIALS AND METHODS

Within the scope of the article , comparisons will be made between different storage systems by performing various simulations in the MATLAB-Simulink program. For this purpose, IEEE 14 busbar and IEEE 30 busbar power systems will be used. Thus, renewable energy plants such as solar and wind and different storage systems will be integrated into two verified different power systems, and the ones with optimum efficiency, their advantages and disadvantages will be examined. As seen in Figure 1, an energy management system will be created, and this system will be created with different hybrid storage technologies. It will be simulated and compared with analytical and intuitive optimization methods. In this way, optimization studies will be carried out to provide maximum energy efficiency with minimum cost.

FINDINGS AND DISCUSSION

Existing batteries have been examined, and the battery types that can store energy from renewable energy sources in the best and most efficient way are lithium-ion, redox flow batteries, and lead acid batteries. The hybrid energy storage system has been determined to consist of a supercapacitor, and this advantageous battery is the best storage method. The characteristics of the batteries and supercapacitors to be included in the hybrid storage system are detailed in Table 1 and Table 2.

In the article by da Silva Lima (da Silva Lima et al., 2021), Table 1 compares lithium-ion and redox flow batteries, with redox flow batteries being considered as an alternative to lithium-ion batteries due to their longer lifespan, better scalability, and safety features.

Parameter	LIB	VRB*
Nominal energy capacity (kWh)	1300.0	37.5
Round-trip efficiency (%)	90.0	83.0
Depth of Discharge (%)	85.0	100
Lifetime (years)	10**	20
Discharged energy after 20 years (MWh)***	5758.0	180.0
Total weight (kg)	17726.7	2215.5
Battery mass fraction needed for discharge of 1 MWh	$3.5 \cdot 10^{-4}$	$5.6 \cdot 10^{-3}$

Table 1. Comparison of Lithium-Ion Battery and Redox flow batteries(da Silva Lima et al., 2021)

In the study by Şahin and Blaabjerg (Şahin & Blaabjerg, 2020), Table 2 provides a detailed examination of the characteristics of lead-acid batteries, lithium-ion batteries, and supercapacitors.

Parameters	Lead-acid Battery	Lithium-ion Battery	Supercapacitor
Specific energy density (Wh/kg)	10–100	150–200	1–10
Specific power density (W/kg)	<1000	<2000	<10000
Cycle life (cycles)	1000	5000	>500000
Charge discharge efficiency	70–85%	99%	85–98%
Fast charge time	1–5 hour	0.5–3 hour	0.3–30 sec
Discharge time	0.3–3 hour	0.3–3 hour	0.3–30 sec
Calendar life (year)	5–15	10–20	20
Cost	100 $/kWh	400 $/kWh	2500 $/kWh

Table 2. Performance analyzes of lead-acid, lithium-ion batteries and supercapacitors (Şahin & Blaabjerg, 2020)

The role and benefits of lithium-ion batteries in hybrid energy storage systems include:

- Network stabilization and frequency regulation.
- Causing high energy density.
- Enabling fast charging/discharging.
- Providing long cycle life.
- Offering modularity and scalability.

Due to their extended lifespan, redox flow batteries are employed in long-term energy storage applications. These batteries' modular structure allow for flexible, efficient, and optimized operation within hybrid energy storage systems. Redox flow batteries with high energy capacity provide an optimal solution for large-scale energy storage systems.

Lead-acid batteries regulate frequencies and ensure balanced operation in hybrid energy storage systems, reducing costs. The functions of a super capacitor in a hybrid energy storage system include providing voltage stabilization, reducing system costs, and extending battery life.

It is necessary to design and install the most efficient storage unit by changing the battery ratios used in specific proportions, considering factors such as the size of the power plant, the amount of power desired to be stored, and environmental effects.

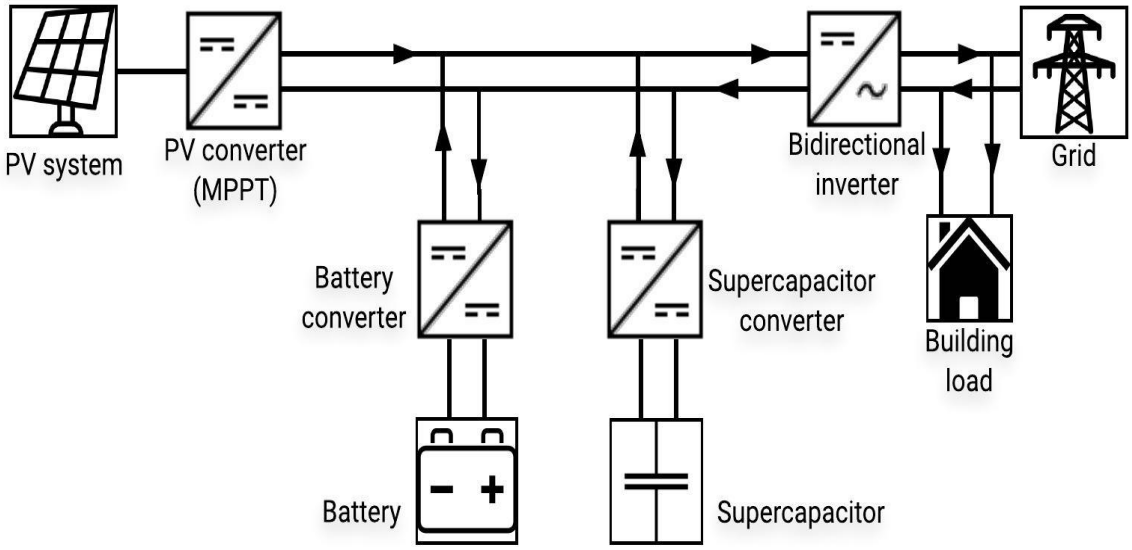

Figure 2. Grid-connected PV system with hybrid energy storage (Argyrou et al., 2018).

CONCLUSION AND RECOMMENDATIONS

The existing batteries have been examined, and it has been determined that lithium-ion, redox flow batteries, and lead-acid batteries are the types of batteries that best and efficiently store the energies of renewable energy sources. A hybrid energy storage system consisting of super capacitors and this advantageous battery has been identified as the optimal storage method. Considering factors such as the size of the energy plant, the desired power storage capacity, and environmental impacts, the battery ratios should be adjusted in specific proportions to design and establish the most efficient storage unit.

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HEAT TRANSFER ANALYSIS IN A STRAIGHT CHANNEL CONTAINING AN EXPANDING CHAMBER WITH WINGLETS

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ABSTRACT

Heat transfer improvement methods remain up-to-date among important research topics as they contribute significantly to energy efficiency and savings. Passive heat transfer improvement methods are widely used in many engineering applications because they do not require additional energy. Therefore, this study aimed to increase heat transfer efficiency by using more than one passive method together. In the presented study, flow and heat transfer characteristics in a straight channel containing an expanding chamber with winglets are numerically analyzed. Analyzes are carried out with ANSYS Fluent software, which provides solutions with the finite volume method. The pressure-velocity connection is handled with the SIMPLE algorithm. There are adiabatic straight sections at the entrance and exit of the channel. The channel structure contains an expanding chamber near the entrance of the channel, and triangular winglets are installed within the chamber. The surfaces of the channel before and after the expanding chamber are flat. The expanding chamber and subsequent channel surfaces are kept at a constant temperature of T_s=340K. Nusselt number (Nu), friction factor (f) and performance factor (PF) are calculated for different Reynolds numbers. The findings of the study are presented as a function of dimensionless numbers. The numerical study is compared with previous study results. To observe the effects of the expanding chamber and winglets on the flow and temperature fields, flow and temperature images in the channel are obtained at different parameters, and the results are discussed. In addition, the study results are compared to the channel without winglets and the straight channel. Numerical results show that the winglets in the expanded chamber increased the heat transfer by improving the flow mixing. However, the presence of winglets causes a slight increase in pressure drop.

Keywords: Expanding chamber, Winglet, Straight channel, Heat transfer improvement, Friction factor.

Introduction

Heat transfer improvement methods provide an important contribution to energy management and savings. For this reason, researchers have been working on this subject for a long time. These methods are divided into three categories: passive, active, and compound methods [1]. Passive methods do not require an additional energy input; therefore, they are safely than other methods [2, 3]. Passive methods are widely used in many heat transfer applications, especially heat exchangers [4, 5]. Wavy/grooved channels are among the most used passive methods [6]. These surfaces enhance the heat transfer performance by increasing the heat transfer area [7]. To date, flow and heat transfer performance in wavy/grooved channels with different groove/wave geometries have been investigated through numerical and experimental studies. The results of these studies have indicated that thermal improvement and pressure drop in wavy/grooved ducts are higher than in straight channels [8-11]. In numerical and experimental study, Ajeel et al. [12] investigated the flow and heat transfer in the circular and trapezoidal wavy ducts and stated that the heat transfer increased by 3.1 times in the trapezoidal wavy channel. Choudhary et al. [13] compared the flow and heat transfer of wavy and straight channels in a heat exchanger and reported that the heat transfer and friction factor were higher in wavy channels than in straight channels. Naderifar et al. [14] numerically investigated the effects of wave number and fin height on the flow and heat transfer in a rectangular wavy duct with fins. Their results indicated that when the wave number is 2 and the fin height is 7.5, the best thermal improvement is achieved compared to the straight channel. Ahmad et al. [15] numerically studied the heat transfer in triangular, sinusoidal, and rectangular corrugated mini ducts with different wave amplitudes, and they found that the heat transfer in the rectangular duct was improved by 22.19% at an amplitude ratio of 0.12.

Another passive method is the addition of baffles or fins/winglets into the duct. Baffles and winglets change the flow structure by directing the flow to certain regions. The addition of winglets in different configurations into the duct enhances the flow and heat transfer [16, 17]. Li and Gao [18] numerically examined the effects of delta-shaped baffles on heat transfer for different apex angles in a triangular wavy bottom wall. They showed that if the appropriate parameters are selected, the Nu can increase by 2.1 and 4.3 times. Sun et al. [19] experimentally and numerically examined the heat transfer of multiple rectangular wings in a circular heat exchanger. Promvonge et al. [20] experimentally and numerically studied the flow and heat transfer of V-type wings. They reported that the wings can increase the heat transfer up to 3.8 times if the appropriate parameters are used. Akcay and Akdag [21] numerically examined heat transfer in a laminar flow conditions in a circular channel with different baffle angles (θ=30º, 90º, 180º). They declared that the highest heat transfer and pressure drop were obtained at the 90º baffle angle. Akcay [22] numerically studied the nanofluid flow and heat transfer in a zigzag wavy channel with winglets and reported that the winglets added to the channel increased the heat transfer and the best thermohydraulic performance was found to be 2.12 at Re=400. Feng et al. [23] numerically examined the flow and heat transfer in the triangular wavy duct with trapezoidal baffles and declared that the heat transfer enhanced by 1.7 times compared to the straight duct, while the pressure drop increased by 3.5 times.

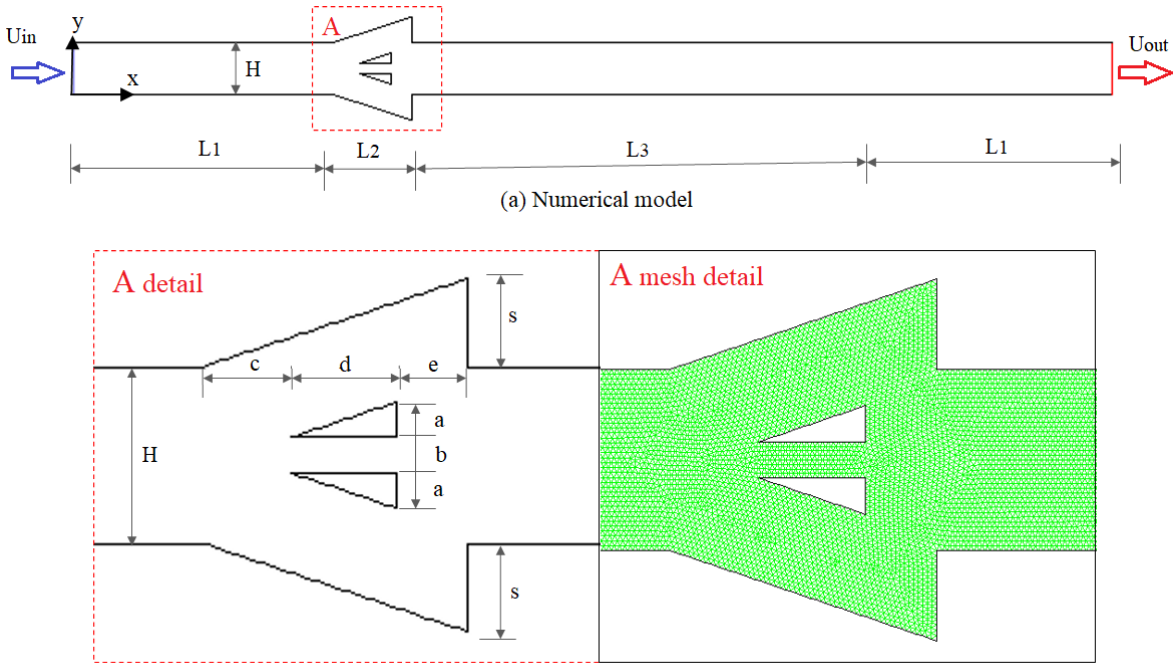
In this numerical study, more than one passive method was used together to further improve heat transfer. In the study, to reduce pressure loss, a large expanding chamber was placed near the entrance of the channel; in this way, the number of grooves was minimized, and the other walls of the duct were kept straight. The purpose of the triangular winglets is to increase heat transfer by improving the flow mixing in the channel. In the context of the study, the flow and thermal characteristics of the laminar steady flow were simulated for different Reynolds numbers ($100 \leq Re \leq 500$) in a straight channel containing an expanding chamber. The results were compared with the straight channel.

Materials and Methods

Figure 1 shows the numerical model used in this study. The channel contains adiabatic straight sections with a length of L_1 = 50 mm at the inlet and outlet. The height of the duct is H_1 = 10 mm. At the channel entrance after the adiabatic section, there is an expanding chamber with a length of L_2 = 15 mm. After the expanding chamber, there is a heated straight section with a length of L_3 = 85 mm, which extends to the beginning of the adiabatic section at the channel outlet. The values of the geometric parameters of the numerical model are given in Table 1.

Table 1. Geometric parameters of the numerical model

Parameter	H	a	b	c	d	e	s	L_1	L_2	L_3
Value	10mm	2mm	2mm	5mm	6mm	4mm	5mm	50mm	15mm	85mm



(a) Numerical model

(b) Detail view and mesh structure of the numerical model

Figure 1. Geometry and boundary conditions of the numerical model

Findings and Discussion

Governing Equations

In the numerical study, the fluid is considered single-phase, incompressible and Newtonian properties. The flow field is 2d. The fluid flows in steady flow conditions and laminar regime. Viscous terms are omitted. Fluid properties are assumed to be constant. The effect of gravity and heat transfer by radiation are not taken into account. According to the these assumptions, governing equations are given below:

$$\frac{\partial u_i}{\partial t} + \nabla(\rho u) = 0 \tag{1}$$

$$\frac{\partial u_i}{\partial t} + \frac{\partial (u_i u_j)}{\partial x_i} = \frac{\partial P}{\partial x_i} + \frac{1}{Re}\nabla^2 u_j \tag{2}$$

$$\frac{\partial T}{\partial t} + u_i \frac{\partial T}{\partial x_i} = \frac{1}{RePr} + \nabla^2 T \tag{3}$$

Numerical Method and Boundary Conditions

The numerical study was carried out using the ANSYS Fluent program. The laminar model was used as the flow model. Governing equations were discretized with the finite volume approach and the velocity-pressure relationship was solved with the SIMPLE algorithm. A value of 10^{-7} was set for all equations as the convergence criterion.

For the mesh independence testing, Nusselt numbers were calculated for different element numbers. As a result of this calculations, it was decided that 51586, and 51418 element numbers are sufficient for the channel without winglets and the channel with winglets, respectively.

Water was used as the working fluid. The fluid enters the channel at a uniform velocity (U) and temperature (T_o=300 K). In the study, Re varies in the range of $100 \leq Re \leq 500$. The heated channel surfaces (L_2 and L_3) were kept constant at T_w=340 K. The non-slip wall condition was defined for the all surfaces. Straight sections at the entrance and exit of the channel are adiabatic. The winglets are assumed to be adiabatic and non-slip conditions.

Data Reduction

The Reynolds number (Re) is calculated by Equation (4):

$$Re = \frac{\rho U D_h}{\mu} \tag{4}$$

where, D_h is the hydraulic diameter, ρ is the density, μ is the dynamic viscosity, and U is the velocity.

The average Nusselt number (Nu) is obtained by Equation (5):

$$Nu = \frac{h D_h}{k_f} \tag{5}$$

where, k_f and h are thermal conductivity coefficient and convective heat transfer coefficient, respectively.

The thermal enhancement (TE) is described with Equation (6).

$$TE = \frac{Nu_w}{Nu_o} \tag{6}$$

where, Nu_w and Nu_o represent the Nusselt numbers obtained in the channel with winglets and the without winglets, respectively.

The friction factor (f) is calculated in the duct is given by Equation (7):

$$f = \frac{2 \Delta P D_h}{\rho U^2 L} \tag{7}$$

Relative friction factor (f_w/f_o) iss obtained by Equation (8):

$$f_{rel} = \frac{f_w}{f_o} \tag{8}$$

where, f_w and f_o are the average friction factors obtained in the channel with and without winglets, respectively.

The performance factor (PF) is obtained by Equation (9):

$$PF = (Nu_w/Nu_o)(f_w/f_o)^{-1/3} \tag{9}$$

Numerical results obtained in this study were compared with the results of previous studies. In their experimental study, Wang et al. [24] investigated flow and heat transfer behavior for the laminar flow of water in a straight channel. Figure 2 shows the comparison of the results of numerical study with the results of Wang et al. [24].

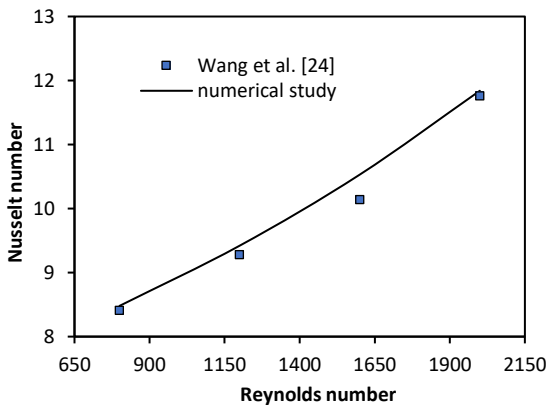


Figure 2. Validation of the numerical study [24]

In Figure 3, the velocity contours are given in channels with and without winglets for Re=100 and Re=500. Re and winglets appear to affect the flow structure. The winglets divided the flow into two main branches. The flow passing around the winglets is directed towards the triangular spaces and is provides better contact with the surface. Increasing the flow velocity increases the mass flow rate and inertia forces. Therefore, increasing the Re ensures a significant contribution to heat transfer.

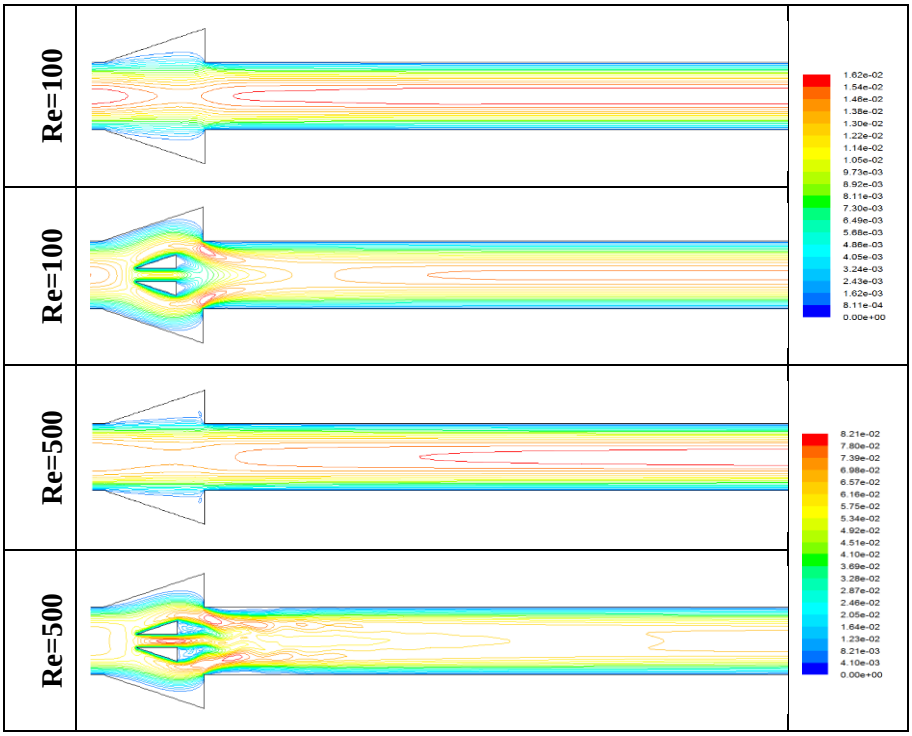


Figure 3. Velocity contours at different Re

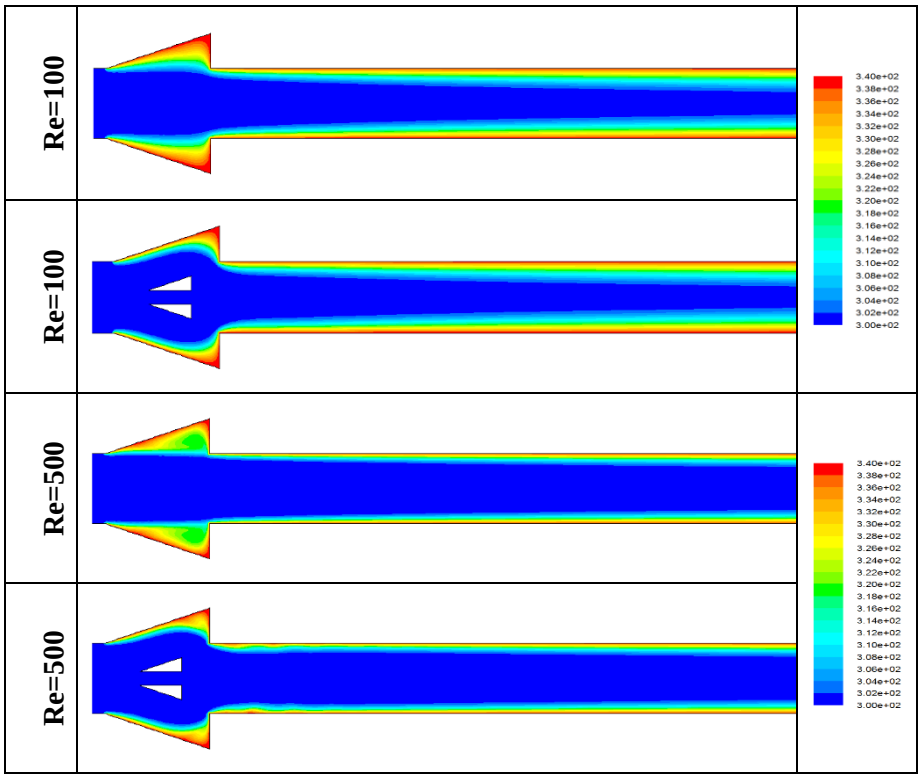


Figure 4. Temperature contours at different Re

In Fig. 4, the temperature contours are indicated in channels with and without winglets for Re=100 and Re=500. Reynolds number and winglets affect the temperature fields. Increasing Reynolds number reduces

the temperature gradient in the channel. It was observed that the surface temperatures in the channel with winglets are lower than in the channel without winglets.

Figure 5 indicates variations of the Nusselt number (a), thermal enhancement (b), friction factor (c), performance factor (d) with Re for all channel cases. In Fig. 5a, the Nusselt number increases as the Reynolds number increases. The highest Nusselt number was found to be 6.04 at Re=500 in the channel with winglets. In Fig. 5b, thermal enhancement in the duct with and without winglets was found to be higher than in the straight duct. The highest thermal enhancement was obtained to be 1.19 at Re=200 in the channel with winglets. In Fig. 5c, as the Reynolds number increases, the friction factor decreases for all channel cases. Friction factors in straight channel and channel without winglets were obtained very close to each other. The friction factor in the channel with winglets was found to be higher than in other channels. The highest performance factor was obtained in the channel without winglets (Fig. 5d). Because the friction factor obtained in the channel without winglets was found to be very close to the straight channel. Performance factor was obtained higher in the channel with winglets than in the straight channel at all Reynolds numbers except Re = 500. The highest PF was obtained to be 1.10 at Re=200 in the channel without winglets.

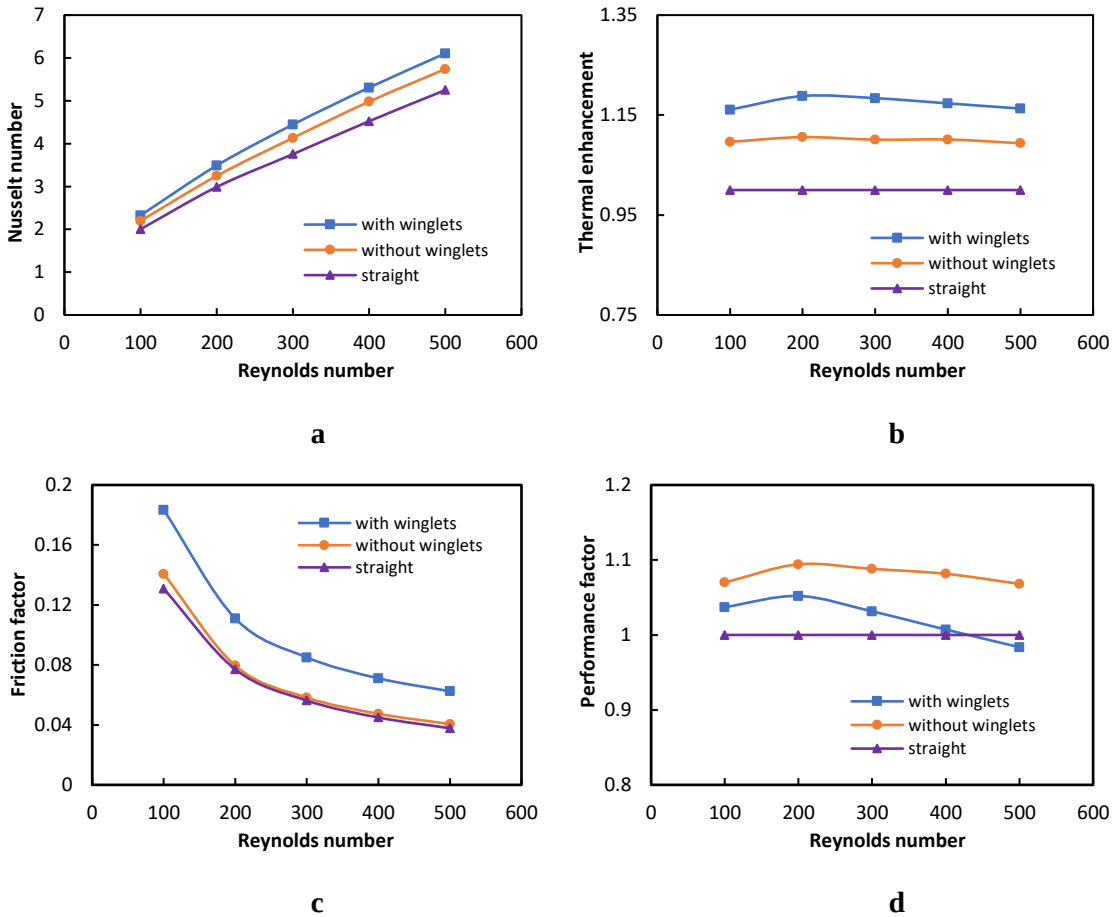


Figure 5. a-Nusselt number, **b-** Thermal enhancement, **c-** Friction factor, **d-** Performance factor with Re

Conclusion and Recommendations

In this study, flow and heat transfer in a straight channel containing an expanding chamber with winglets are numerically analyzed. Nusselt number (Nu), thermal enhancement (TE), friction factor (f) and performance factor (PF) were calculated for different Reynolds numbers. To observe the effects of the expanding chamber and winglets on the flow and temperature fields, velocity and temperature contours in the channel were obtained at different parameters. In addition, the study results were compared with the channel without winglets and the straight channel. The important findings of the numerical study are given below:

- The winglets in the expanding chamber increased the heat transfer by improving the flow mixing. However, the presence of winglets causes a slight increase in pressure drop.
- The highest Nu was obtained to be 6.04 at Re=500 in the channel with winglets.
- The highest TE was obtained to be 1.19 at Re=200 in the channel with winglets.
- Friction factors in straight channel and channel without winglets were obtained very close to each other.
- The friction factor in the channel with winglets was found to be higher than in other channels.
- The highest PF was obtained to be 1.10 at Re=200 in the channel without winglets.

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PRODUCTION OF POLYESTER RING SPUN YARNS WITH THERMOREGULATING FUNCTION CONTAINING MICROENCAPSULATED PHASE CHANGE MATERIALS (PCM) FOR PERSONAL THERMAL MANAGEMENT (PTM) APPLICATIONS

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ABSTRACT

Thermoregulation is defined as the ability of textile material to keep the temperature constant under dynamic external environment. Thermoregulation affects thermal comfort of human body and hence energy consumption due to the requirement of building heating, ventilation, and air conditioning (HVAC). Phase change material (PCM) incorporated textiles offer buffering effect under sudden temperature changes by maintaining the body temperature constant and thus providing prolonged thermal comfort. PCM integrated textiles provide personal thermal management (PTM) by keeping the body temperature constant instead of cooling/heating the entire building space. In this work, it was aimed to produce PCM nanocapsule integrated polyester spun yarns that can be used for thermal regulation and personal thermal management (PTM) textile applications. PCM nanocapsules with gelatine-gum Arabic walled and n-octadecane core were synthesized by complex coacervation method and applied to polyester staple fibers via a specially designed application method during ring spun yarn production. Prior to the application, at first, nanocapsule dispersions were prepared at 6% PCM nanocapsule concentration. And then, PCM nanocapsule dispersion was applied to the polyester fiber bundle during the drafting process of the ring spinning by using two different feeding rates varying between 62.5 mL/h and 80 mL/h, and Ne 30/1 polyester ring spun yarns with knitted twist (αe=3.4) were produced. Morphological properties of the produced polyester ring spun yarns were analysed by Scanning Electron Microscope (SEM) images. Thermal properties of the PCM nanocapsule incorporated yarns were measured by the Thermal-History (T-History) test method and the changes in surface temperatures of yarn samples were analysed. SEM images showed that PCM nanocapsules could be integrated into the yarn structure and hence PCM nanocapsule incorporated polyester ring spun yarns provided lower surface temperatures compared with virgin yarn during all the measurement process. It was determined that PCM incorporated yarns exhibited thermoregulation function more than 2 °C compared to unloaded virgin yarns. With respect to the analysis results, obtained novel heat storage polyester yarn is a promising material for thermal energy storage and desirable thermal comfort applications.to the internal structure of the yarn.

Keywords: Personal thermal management (PTM), energy saving, thermoregulating textiles, phase change materials (PCMs), functional yarn, polyester fiber.

Introduction

Thermal comfort expresses satisfaction with the thermal environment and means that a person feels neither too cold nor too warm. It is significant to maintain thermal comfort because thermal conditions of human body are crucial for physical and psychological health of the human. In addition, lack of thermal comfort may cause reduction in industrial labor productivity and eventually economy. Furthermore, regulating human body thermal comfort wisely shows a significant effect on saving energy consumption of building heating, ventilation, and air conditioning (HVAC) systems. For instance, to maintain human body thermal comfort in a 2 °C expanded heating/ or cooling set-point range can realize approximately 20% of HVAC energy saving. To realize improved human body thermal comfort and also to reduce energy consumption on building heating and cooling, personal thermal management (PTM) considered as a promising solution. PTM technologies provide local thermal envelope around human body instead of cooling/heating of the entire building space.

Therefore, they have great potential for reducing building energy use and satisfying individual's thermal comfort. PTM technologies have the potential to achieve 15–30% energy saving in buildings (Hu et al., 2020; Peng and Cui, 2020).

In recent years, incorporation of phase change materials (PCMs) to the textile materials attracts the attention of researchers to realize thermoregulation and personal thermal management (PTM). Generally, the PCMs utilized in textiles exhibit high enthalpy of fusion. They can store and release thermal energy at an almost constant temperature. When they expose to high temperature, PCMs undergo the liquification process accompanied with a huge amount of energy adsorption when they reach their melting points. In reverse, solidification process happens releasing latent heat when temperature of PCMs arrives at the crystallization point as temperature decreases (Alva et al., 2017). Absorbing or releasing latent heat of PCMs enables thermo-regulating and temperature buffering effects for human body (Peng and Cui, 2020). In textile field, PCMs have been used as a microencapsulated form and they can be microencapsulated by many different microencapsulation techniques. Many different core-shell materials can be used for microencapsulation of PCMs. Particularly, organic core (like paraffin) and shell materials are the most popular choice (Alva et al., 2017).

In this work, it was aimed to investigate the effect of PCM nanocapsules on thermoregulation function of polyester ring spun yarns. PCM nanocapsules were produced with complex coaservation method. Nanocapsules with gelatine-gum Arabic walled and n-octadecane core were synthezised by complex coacervation method. PCM nanocapsules were incorporated to polyester fibers during yarn spinning via specially developed application method. Prior to the application, at first, nanocapsule dispersions were prepared at 6% PCM nanocapsule concentration, as described in previous study (Yılmaz et al., 2023). And then, PCM nanocapsule dispersion was applied to the polyester fiber bundle during the drafting process of the ring spinning by using two different feeding rates varying between 62.5 mL/h and 80 mL/h, and Ne 30/1 polyester ring spun yarns with knitted twist (αe=3.4) were produced. Morphological and thermal properties of the produced polyester ring spun yarns were analysed.

Microencapsulated PCMs can be integrated to the textiles by different methods. These methods focus on fiber spinning based on mixing PCMs with polymer and coating based on pad-dry-cure or lamination etc. Therefore, a common method for applying PCMs to staple fibers has not yet been presented. In literature, there are relatively few studies on PCM microcapsule integrated staple spun yarns. In these studies, researchers used various methods based on core-spun, wrap and friction yarn spinning and a core material was often coated with PCM capsules and wrapped with staple fibres (Yu et al., 2022; Lin et al., 2016; Marsal, 2012). Different from these studies, in this study, no core yarn was used and it was focused on the application of PCM microcapsules inner structure as well as the outer surface of the yarn structure to get better thermo thermoregulationregulation function.

Materials and Methods

Materials

PCMs are capable to sense the stimuli from the environment by storing heat in case of hot environment and releasing the absorbed heat energy in cold environment (Pauken, Emis, & Watkins, 2007). PCMs change its phase from liquid to solid and vice versa during melting and crystallization process and hence it cannot be integrated into textiles without encapsulation. To overcome leakage problem during the solid-liquid phase transition and to prevent the reaction of the PCMs with the surrounding environment, PCMs are widely microencapsulated (Mondal, 2008) and various methods are often used for covering or encapsulating the core/active material such as PCM into a protective wall. Therefore, polymerization method and core material is important in microcapsule production to improve the heat storage performance of the encapsulated PCMs. In this study, complex coacervation polymerization method and n-octadecane core material was used for the encapsulation of PCM. PCM nanocapsules with gelatine-gum Arabic walled and n-octadecane core were produced by complex coacervation method. A wall/core ratio of 1/1 was used in the production of PCM capsules. Morphological structure of the produced PCM capsules was characterized by LEO 440 Computer Controlled Digital Scanning Electron Microscope (SEM) while thermal properties were analysed by Differential Scanning Calorimetry (DSC). DSC analysis was realized in nitrogen (N2) atmosphere at a heating/cooling rate of 10 °C/min between -5 °C and +80 °C using the Perkin-Elmer Jade DSC device. Particle Size Analyzer (Malvern Brand MS2000E model) was used for the determination of particle size and size

distribution of PCM capsules. The results were given in previous study and it was determined that the capsules had ideal spherical morphology, uniform particle sizes varied from 150 nm to 400 nm. The heat storage capacity of nanoencapsulated n-octadecane core with gelatin-gum Arabic wall was 63 j/g during solid-liquid phase transition at 25.9 °C. They released -67.97 j/g latent heat during at 25 C during crystallization (Yılmaz & Alay Aksoy, 2023).

PCM nanocapsules were incorporated to polyester fibers during yarn spinning via specially developed application method. Polyester fiber was selected due to its widely used in wide range textile products from clothing to industrial products. Polyester fiber length was 38 mm and fiber fineness was 1.4 dtex.

Method

An alternative application method was used for the application of PCMs. Main idea of the method was based on the integration of PCM microcapsule dispersion to the open fiber bundle prior to spun yarn formation. With open fibre bundle application, PCM capsules could be integrated to the fibres in the inner structure and outer surface of the yarn. For the application, a specially designed feeding apparatus was used. Prior to the application, at first, nanocapsule dispersions were prepared at 6% PCM nanocapsule concentration, as described in previous study (Yılmaz et al., 2023). And then, PCM nanocapsule dispersion was applied to the polyester fiber bundle during the drafting process of the ring spinning by a specially designed feeding apparatus. PCM nanocapsule dispersion was applied to polyester fiber bundle in a controlled manner at specific feed rate values. In the study, two different feeding rates varying between 62.5 mL/h and 80 mL/h were used. Ne 30/1 polyester ring spun yarns with knitted twist (αe=3.4) were produced.

Test and Analysis

Morphological properties of the produced polyester ring spun yarns were analysed by Scanning Electron Microscope (SEM) images. SEM images were analysed to determine the presence of PCM in the yarn structure. Thermal properties of the PCM nanocapsule incorporated yarns were measured by the Thermal-History (T-History) test method and the changes in surface temperatures of yarn samples were analysed (Yılmaz et al., 2023; Alay et al., 2017). Dynamic temperature regulation feature of the samples was evaluated resulting from absorbed latent heat by the nanoencapsulated PCMs in the yarn structure in variable temperature environments.

Findings and Discussion

1) Yarn images

Longitudinal and cross-sectional images were taken from PCM integrated polyester ring spun yarns to determine the presence of PCM nanocapsules in the yarn structure. According to longitudinal views, PCM nanocapsules were attached to the surface of the polyester fibres. The presence of capsules along the fibre length could be clearly seen. Even, PCM capsules were observed in almost all fibres. However, the capsules were agglomerated. Particle size of capsules was getting larger due to PCM nanocapsule agglomeration. Decreasing particle size might be main reason for clustering tendency. As the particle size decreases, adhesion force between the particles also increases. This case might particle agglomeration tendency (Urbas et al., 2017). Cross-sectional images were taken from PCM capsule applied polyester ring spun yarns. As seen in Figure 2, PCM nanocapsules were observed on the surface of each fibre. Therefore, longitudinal and cross-sectional images of the produced yarns indicated the presence of PCM nanocapsules on the surface of the fiber and hence they were placed the inner and outer structure of the yarn.

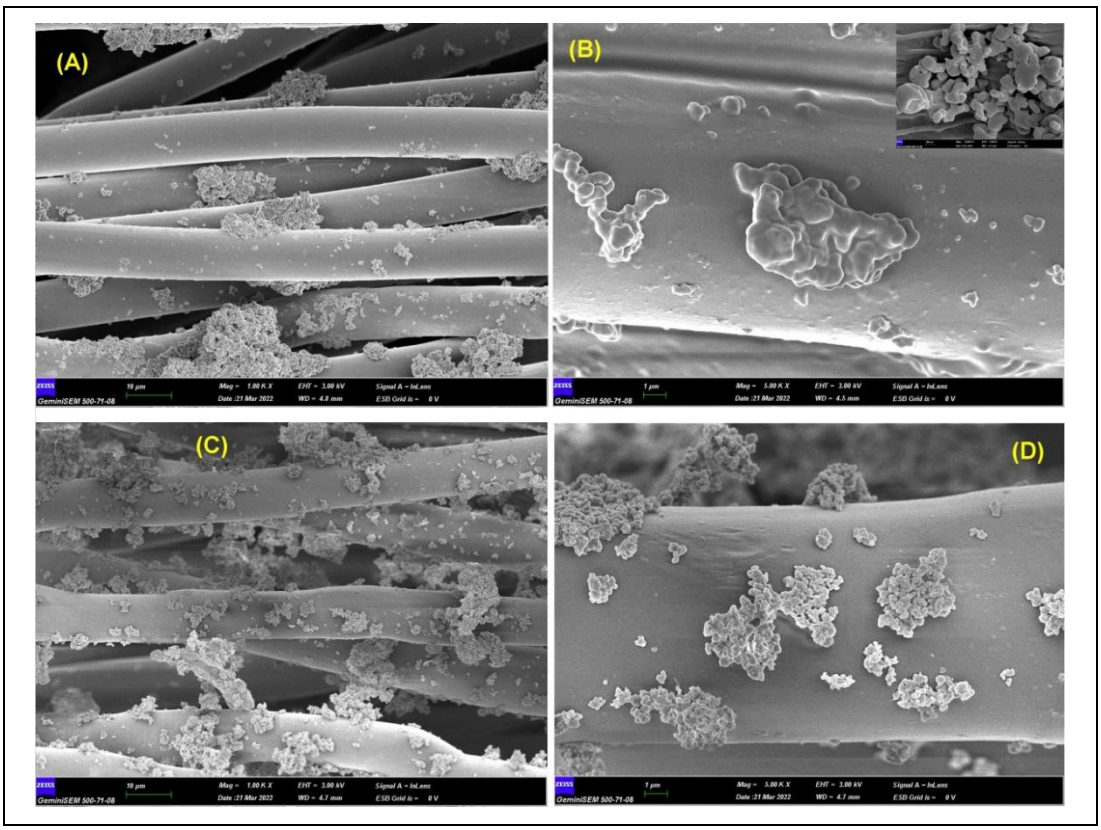

Figure 1. SEM images of PCMs incorporated polyester ring spun yarns (A, B: Yarn samples produced at 62.5 mL/h, C, D: Yarn samples produced at 80 mL/h)

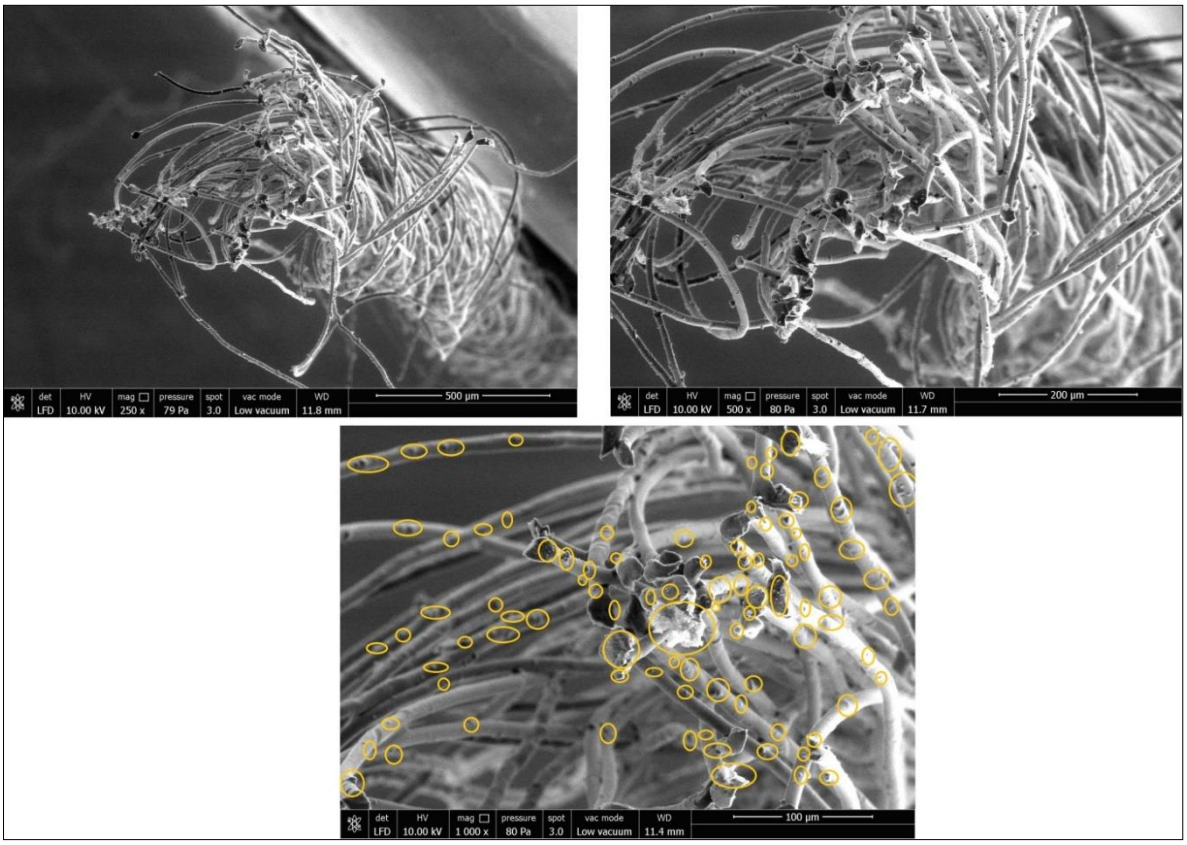

Figure 2. Cross-sectional images of PCMs integrated polyester yarns at 80 mL/h

2) Thermal properties of the yarns

Thermal properties of unloaded virgin and PCM nanocapsule integrated polyester ring spun yarns were analysed by Thermal History (T-History) test method. Before the measurement, all the yarn samples were firstly conditioned and then temperature changes on the yarn surfaces were measured with a thermal camera during the heating of the sample in a warm insulated box. The time-dependent graphs (T-history graphs) of the temperatures were measured every 15 seconds with a thermal camera. After the measurement, T-History graphs were drawn. In the graphs, y-axis shows the temperature measured on the surface of the yarn sample while x-axis shows the measurement time. By the graphs, the tendency of the temperature change of the samples was determined as a function of time. At the same time, the difference between the temperature values of unloaded virgin and PCM nanocapsule integrated yarns at a certain measurement time was calculated using the data of T-history measurements. In Figure 3, T-history graph was given for the unloaded virgin and PCM nanocapsule integrated polyester yarns having gelatin-gum Arabic wall and n-octadecane core capsules. According to the T-History test results, all capsule integrated polyester yarns produced with two different nanocapsule feeding rate values had lower surface temperature values compared to unloaded yarn. Hence, PCM-loaded yarns provided a lower surface temperature values.

During the warming-up period, the surface temperature of the yarns without nanocapsules increased rapidly to 21.2 °C in the first 10 minutes. After this point, it warmed up slowly and reached a maximum of 35.5 °C at the end of the measurement period (1 hour 5 minutes). While the surface temperature of the PCMs integrated yarns increased to 12.3-13.1 °C in the first 10 minutes. After this point, it warmed up similarly slowly and reached a maximum of 31.0-33.8 °C at the end of the measurement period.

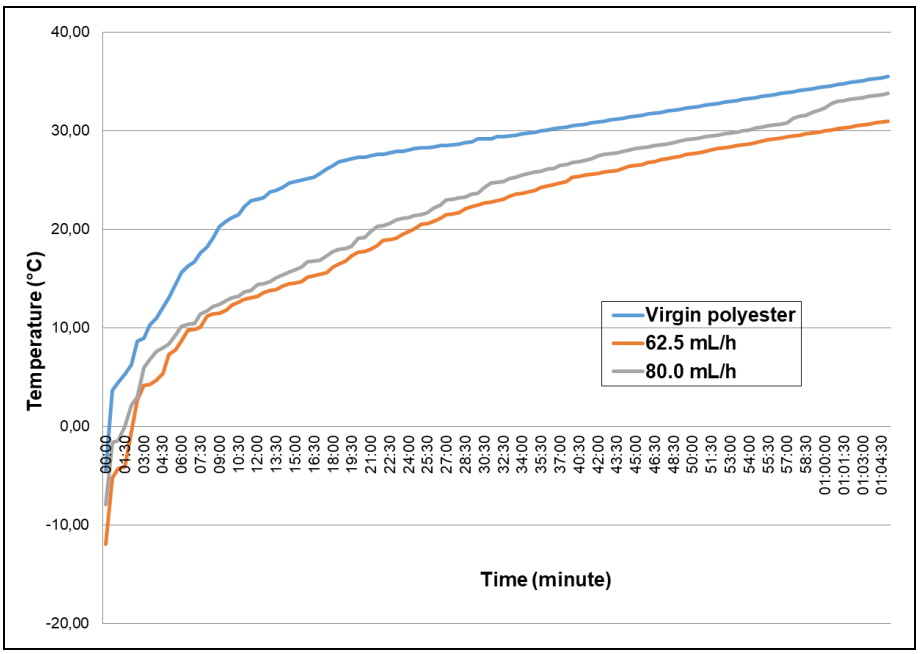

Figure 3. T-history curves of virgin and PCM nanocapsule incorporated cotton ring spun yarns

In Table 1, it was given the difference values between the surface temperatures of unloaded virgin and PCM nanocapsule integrated polyester ring spun yarns at different measurement times. When the results were evaluated, it was observed that PCM nanocapsule loaded polyester yarns provided higher temperature difference values in the warming-up period, while in the saturated surface temperature region, temperature difference values were achieved at a lower level. Particularly, the decrease in the temperature difference in the saturated temperature region was higher for 80 mL/h feeding rate. Temperature difference value was about 4.5 °C for 62.5 mL/h while it was determined as 1.7 °C for 80 mL/h at the end of the measurement. Mean surface temperature differences at 62.5 mL feeding rate value were about 6.4 °C while it was 4.9 °C at 80 mL/h. Contrary to expectations, higher temperature difference values were obtained at a lower feeding rate. Actually, obtaining high temperature difference values with lower feeding rate offers advantages in terms of cost,

chemical and water consumption. The agglomeration of the capsules and the saturation of the yarn structure might be the reasons why high temperature difference values could not be obtained at higher feeding values.

Thermal measurements showed that polyester yarns provided an average temperature difference between 4.9-6.4 °C and exhibited thermoregulation performance after the PCM nanocapsule application with the developed method.

Table 1. Differences in surface temperatures (ºC) of virgin and PCM nanocapsule incorporated polyester ring spun yarns at different feeding rates

Measurement time (minute)	62.5 mL/h	80.0 mL/h
05:00	5.80	4.70
15:00	10.3	9.00
30:00	6.70	5.50
45:00	5.00	3.30
01:00:00	4.50	2.20
01:05:00	4.50	1.70

Conclusion and Recommendations

In this work, it was integrated PCM nanocapsules to the polyester staple textile fibres and produced ring spun yarns that can be used in textile products for thermal regulation and personal thermal management (PTM). PCM nanocapsules with gelatine-gum Arabic walled and n-octadecane core were produced by complex coacervation method and applied to polyester fibers via a specially designed application method during ring spun yarn production. SEM images of the produced PCM integrated polyester yarns showed that PCM nanocapsules could be integrated into the yarn structure and nanocapsules were available from the internal and external structure of the yarn. Due to the PCM nanocapsules in the yarn structure, thermal measurements indicated that PCM nanocapsule integrated polyester ring spun yarns provided lower surface temperatures compared with virgin yarn during all the measurement process. Polyester yarns provided an average temperature difference between 4.9-6.4 °C and exhibited thermoregulation performance. High latent heat and capacity for energy transfer feature of PCM nanocapsules enhanced the temperature difference to the PCMs integrated yarns. This case was considered as a cooling effect of PCM in yarn structure. With respect to the analysis results, obtained novel heat storage polyester yarn is a promising material for thermal energy storage and desirable thermal comfort applications.

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EXPERIMENTAL INVESTIGATION OF DRYING AND ENERGY PERFORMANCE IN A CONDENSER TUMBLE DRYER

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ABSTRACT

With the advancement of technology, machines ubiquitous in almost every aspect of our lives make our daily routines more comfortable. These routines can sometimes give rise to needs. However, the increasing number of machines in response to growing demands also leads to a rise in energy consumption. Appliances, nearly present in every household and significantly contributing to energy consumption, are the focus of numerous studies. Consequently, energy classes are becoming increasingly stringent, urging engineers to develop more efficient machines. Energy savings are achievable to the extent that the system performance of machines can be enhanced.

In this study, the focus has been on the tumble dryer within the white goods product group. Electric tumble dryers generally come in three different types: vented, condenser, and heat pump dryers. In the scope of this study, the drying and energy performance of a condenser tumble dryer has been examined through experimental methods. Experimental studies include energy performance tests of the existing machine, temperature data obtained with thermocouples, and flow measurements of air cycles. The results obtained for the existing machine are compared with the results of experimental studies with different configurations. At the end of the experimental studies, the drying performance has been improved from around 3.3 % to 1.1 %, and the energy consumption has also been improved by approximately 4.5 %.

Keywords: Tumble Dryer, Condenser Tumble Dryer, Energy Efficiency, Drying Performance.

Introduction

With the development of the industry, tumble dryer machines have found their place in homes. With the increasing prevalence of use, laundry drying machines have begun to play a significant role in energy consumption (Conde M.R., 1997). Tumble dryers are devices that allow textiles to be dried in the desired quantity and at the desired time. Thanks to their contributions to evolving technologies, tumble dryers are devices that are continuously worked on and subject to ongoing development activities.

Electric tumble dryers are essentially available in the market with three different systems. These are, in order of development: vented tumble dryers, condenser tumble dryers, and heat pump tumble dryers. The two types of dryers that use electric heaters are vented tumble dryers and condenser tumble dryers. The concept in heat pump tumble dryer is related to the refrigerant cycle of the compressor. Vented tumble dryers send the drying air, which has passed through the electric heater, to the drum. The drying air, which absorbs moisture from the wet laundry inside the drum, first passes through a filter and is then expelled outside the machine through a duct. The drying air is continuously drawn in from the outside (Cochran et al., 2009). The studies indicate that vented tumble dryers are inexpensive, reliable, and relatively fast; however, it has also been determined that to avoid moisture problems, the machine needs to expel humid air outside the room (Bansal et al., 2001). In a similar context, it has been stated that vented dryers are not preferred in cooler climates because the energy content of the warm dryer air is lost, and the net air loss from the house must be compensated by the household heating system (Cochran et al., 2009).

Methods to reduce energy consumption in the tumble dryers process have been investigated. In one study, the impact of drying air and cooling water on the drying rate and energy efficiency of tumble dryer has been

examined (Lee et al., 2006). In yet another study, heat pump tumble dryers with energy efficiency 40% higher than electric tumble dryers have been investigated (Braun et al., 2002). In a separate study, factors influencing the energy performance of vented tumble dryers have been examined, including fan speed, drum rotation speed, total weight of clothes, and heating power (Bassily, A. M., & Colver, G. M., 2003). Another study defines the mass transfer with clothes inside the drum, establishing a relationship with drum speed, weight of clothes, Reynolds number, Gukhman number, and Schmidt number based on experimental results (Bassily, A. M., & Colver, G. M., 2003).

Condenser machines have two separate circuits, one closed and the other open. The closed circuit represents the cycle of the drying air, while the open circuit involves drawing air from the environment, passing it through the fins of the condenser to absorb heat, and then returning it to the room. The condensation process in the condenser occurs during the cooling cycle, and the condensation itself is related to the drying air that heats up in the electric heater, absorbs moisture from the laundry, and releases moisture into the condenser channels along with a temperature loss.

In the literature, there are studies on increasing the energy and drying performance of condenser drying machines by working on the heating capacity, the flow rate of drying air, and the flow rate of cooling air (Do et al., 2013). In another study conducted for a condenser machine, an approach was established through one-dimensional system modeling. In this approach, with all other inputs held constant, the effect of the airflow rate and temperature of the cooling air on the condensation ratio of the condenser machine was examined (Yıldıran, V.C., & Güneş, H., 2023)[1]. In another study, the relationship between the increase in cooling fan efficiency and the increase in the airflow rate of the cooling air was investigated, followed by an analysis of the machine's energy consumption and drying performance (Yıldıran, V.C., & Güneş, H., 2023)[2].

Within the scope of this study, the condenser tumble dryer, frequently preferred for drying textiles in homes, has been experimentally examined. In the experimental investigations, the key outputs of the machine, including drying performance and energy consumption, have been scrutinized. In this study, the heating power and the flow rate of drying air were kept constant, and the focus was solely on increasing the flow rate of cooling air and reducing its temperature.

Materials and Methods

The study commenced with energy performance tests conducted in the laboratory. The machine underwent testing at the Haier Europe Energy Performance Laboratory, adhering to the EN 60456 and IEC 61121 standards. The results of these tests provided insights into the machine's energy consumption, drying performance, water collection and drying time (Figure 1). Additionally, essential data such as the temperature and airflow rate of cooling and drying air were measured during laboratory tests. An anemometer was used to measure the flow rates of the drying and cooling air in the machine, while thermocouples collected temperatures from significant areas on the machine throughout the entire drying cycle.

Fig. 1: Test Corner of Energy Performance Laboratory and DAQ Screen of Measurements

The front fan for cooling air, rear fan for drying air and drum are associated with the rotation of the motor. All tests have been completed under full load standard for the 10 kg capacity machine to observe the worst condition. Flow rate measurements have been taken for the machine in its fully loaded state.

Anemometer and some specialized equipment are used for measuring the flow rates of cooling air and drying air (Figure 2).

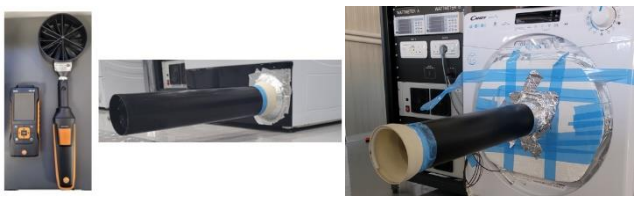

Fig. 2: Anemometer and Flowmeter Devices

To investigate temperature fluctuations throughout the drying cycle, thermocouples were positioned at the condenser's inlet and outlet for the cooling air, as well as at the inlet, outlet, and heater exit for the drying air (Figure 3 and Figure 4).

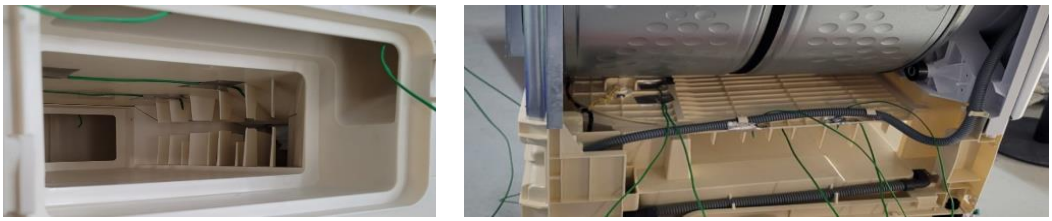

Fig. 3: Thermocouple Positions of Cooling Air Condenser Inlet and Outlet

Fig. 4: Thermocouple Positions of Drying Air Condenser Inlet, Outlet and Heater Outlet

It was previously mentioned that the condenser drying machine has two different cycles. These include the closed loop drying cycle. The air heated in the heater passes over wet laundry, extracting moisture from the clothes. Subsequently, the drying air, which reaches the condenser channels after passing through the filter, loses its heat and releases moisture in the condenser channels. The cooling air, on the other hand, is an open-loop cycle. The cooling air is taken from the room environment and sent to the condenser fins through a fan. It absorbs heat from the condenser without mixing with the drying air. Passing through the condenser fins and increasing in temperature, the cooling air is returned to the room environment. The theoretical location of condensation is the condenser (Figure 5).

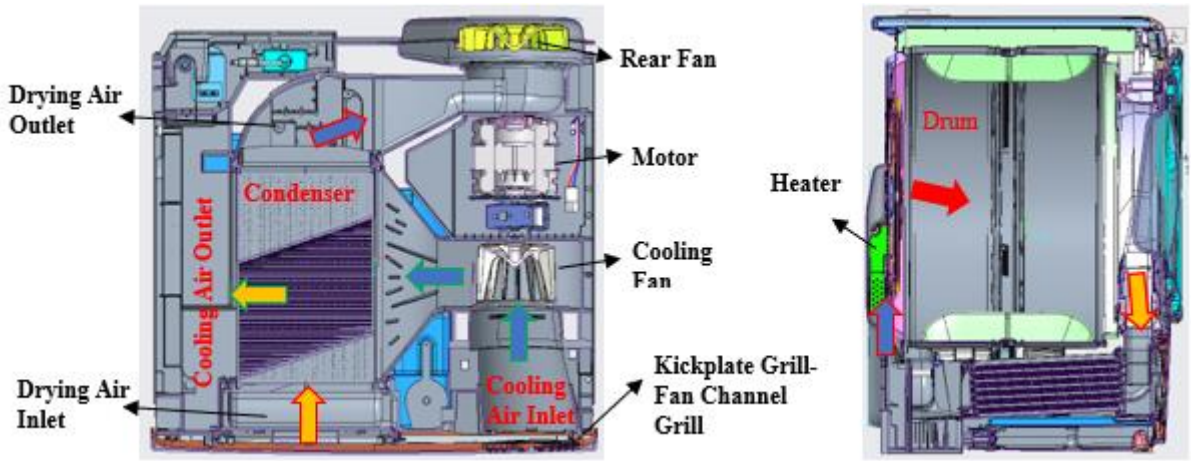

Fig. 5: Drying and Cooling System on Sections

In theory, the humid air carried by the drying air condenses in the condenser channel. The condensation is achieved by the cooling air extracting heat from the condenser fins. The fins of the condenser and the channels are used in a closely interconnected manner. This allows heat transfer between the two air streams, which flow in a crosscurrent without mixing with each other (Figure 6).

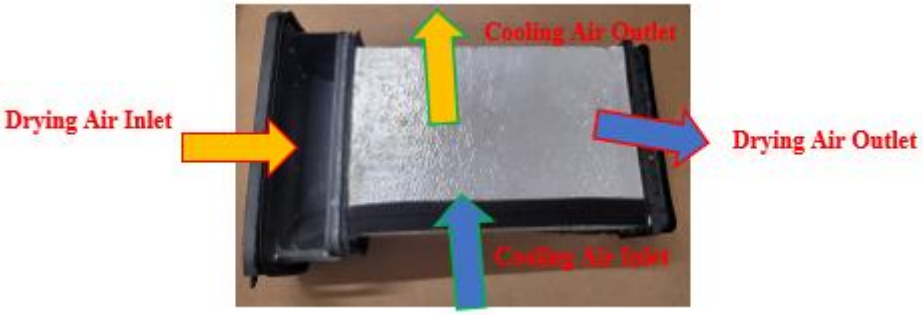

Fig. 6: Condenser of Tumble Dryer

Experimental studies have been conducted to investigate the drying and energy performance of the existing condenser tumble dryers following energy performance tests. These studies are based on keeping the heating power and fan speeds constant, focusing solely on variations in flow rate and cooling air temperature for the cooling side. Each test has progressed to include the previous modification as well.

The first modification is made in the fan channel of the cooling air. With this modification, the efficiency of the fan has been increased from 44 % to 51 % (Figure 7). The increase in fan efficiency has led to an increase in the cooling air flow rate 3%, while reducing the energy consumed 12 % by the fan (Yıldıran, V.C., & Güneş, H., 2023)[2].

Fig. 7: 3D Printing of Inner Part and Assembling the Cooling Fan Channel

The second study is related to the cooling fan grill. To increase the flow rate of the cooling air, it was desired to reduce the resistance in the grill. Grill surface area was increased 27 % (Figure 8).

Fig. 8: Current and Modified Cooling Channel Grill

The third study involves creating a channel between the kickplate grill and the cooling channel grill. This is intended to prevent the direct intake of air from the room environment and to prevent the absorption of the hot air trapped between the kickplate and cooling fan grilles. The goal of this modification is not to increase the flow rate but to lower the temperature of the cooling air (Figure 9).

Fig. 9: Modified Kickplate with Channel

The fourth modification involves the complete removal of the kickplate grill and the reduction of resistance altogether. Serious resistance occurs due to the two-stage grills (Figure 10).

Fig. 10: Modified Kickplate without grill and Modified Cooling Fan Inlet Grill

The fifth modification is related to a change that allows the cooling air to be directly released into the room environment after leaving the condenser fins in order to decrease the temperature of the condenser. In the current model, some of the air separated from the condenser fins is distributed inside the machine, while some exits the machine through gaps in the side wall. With the modification, the air is directly expelled outside the machine (Figure 11).

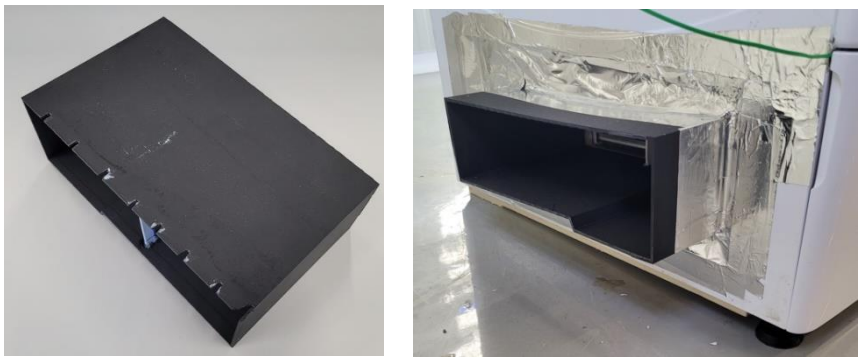

Fig. 11: Vent for Cooling Air Outlet of Condenser

Findings and Discussion

Each modification in experimental studies has progressed by being added on top of another. To eliminate possible inconsistencies in the test results, the tests were repeated seamlessly three times, and averages were taken. The tests were conducted under full load conditions. Flow measurements and temperature measurements have been completed for all tests.

The existing model with no changes is named Model A. Only the modification made inner part of cooling channel is labeled as Modification B. Keeping Modification B and adding modified grill of the cooling channel is labeled as Modification C. For Modification D, a channel modification has been made to close the gap between the kickplate grill and the cooling channel grill. The grill form on the kickplate has been eliminated, keeping other modifications constant, and it is named Modification E. In the final modification, all other modifications were kept constant, and a vent was added to the cooling air outlet of the condenser, labeled as Modification F (Table 1).

Table 1. Test Results

Modification	A	B	C	D	E	F
Flow Rate [m^3/h]	92.7	95	106.8	106.8	131.8	131.8
Drying Perf [%]	3.33	2.52	1.1	1.43	0.97	0.89
Time [min]	193	193	193	191	190	192
Energy [kWh]	5.81	5.80	5.83	5.86	6.00	5.99
Normalized Time [min]	205	201	196	195	192	195
Normalized Energy [kWh]	6.17	6.04	5.91	5.96	6.04	6.09
Cooling Inlet [°C]	37.9	39	38.1	36.3	33.7	33.2
Process Inlet [°C]	71.7	72.3	71.1	70.5	67.5	68.7
Process Outlet [°C]	68.0	68.1	66.6	66.2	63.2	64.2
ΔT Process [°C]	3.7	4.1	4.5	4.3	4.3	4.5
Heater Energy Consumption	5.34	5.30	5.33	5.36	5.47	5.55
Heater on Time [min]	165.4	164.6	165.7	166.5	169.9	172.2

After the completion of the tests, the results were examined. Minitab software was utilized for the analysis of experimental results.

Experimental studies are fundamentally focused on examining energy performance and drying performance by keeping the heating power constant, increasing the air flow rate of the cooling air, and reducing the temperature of the cooling air. To enhance condensation performance, an increase in the temperature drop of the drying air was desired (Figure 12).

Initially, the impact of the cooling air flow rate and the temperature of the cooling air on the drying air temperature differences was analyzed. While both data are effective in the temperature change of the drying air, it has been observed that the flow rate of the cooling air is more influential than the inlet temperature of the cooling air to the condenser (Figure 12).

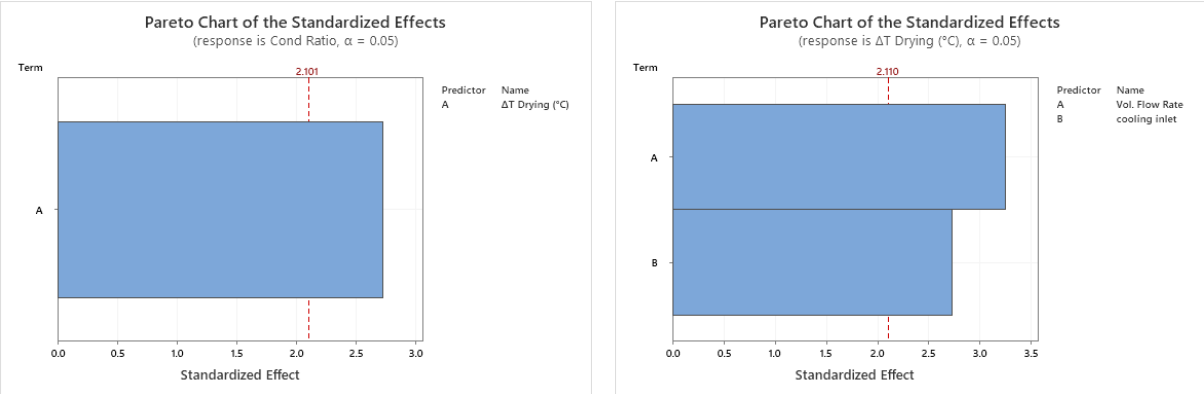

Fig. 12: Relationship Between Condensation Ratio - Drying Air Temperature Differences and Drying Air Temperature Differences - Cooling Air Volume Flow Rate with Inlet Temperature

The examination reveals that the increase in the cooling air flow rate and the decrease in the inlet temperature of the cooling air to the condenser have a clear impact on drying performance. However, in experimental studies, it has been observed that as the cooling efficiency increases, the exit temperature of the drying air from the condenser decreases, leading to an increase in energy consumption. Therefore, analyses have been conducted on the relationship between the exit temperature of the drying air from the condenser (Figure 13).

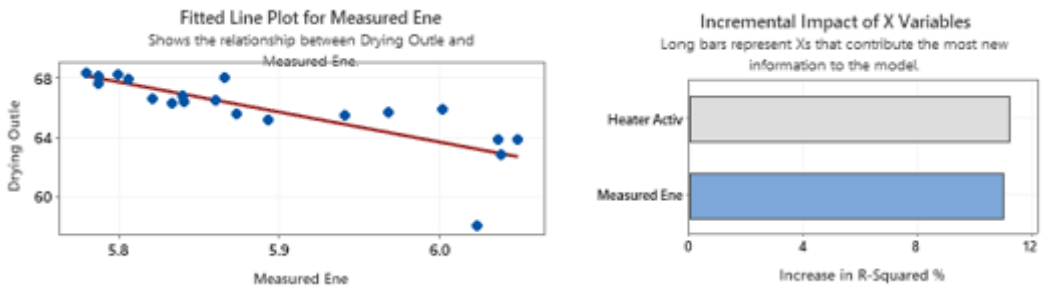

Fig. 13: Multiple Regression for Drying Outlet

It is evident that the main source of energy consumption in the condenser drying machine is the electric heater. For these experimental tests, a 2100-watt heater was used, and the relationship between the duration of the heater being active and energy consumption has been examined. (Figure 14).

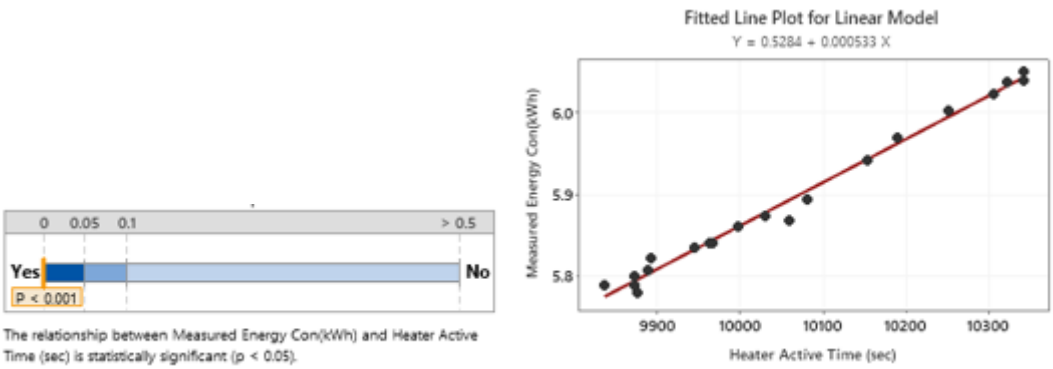

Fig. 14: Regression for Measured Energy vs Heater Active Time

Normalized values are also present along with the measured values throughout the drying cycle of the machine. The normalized values, at the end of the drying cycle, encompass the revision of energy consumption and drying time based on the drying rate result. In the case of a zero-drying rate, calculations are made to determine how energy and time would change. As a declaration at the end of the machine's drying cycle, the drying rate, nominal energy consumption, and nominal drying time are provided. Therefore, nominal values have been taken into consideration when examining the results.

The results of the experimental study have been examined, and relationships between the data have been established. The results were re-evaluated to select the optimal modification among the conducted studies. Here, all modifications were assessed, and graphs were plotted based on the shortest duration, the highest drying rate, and the lowest energy consumption (Figure 15).

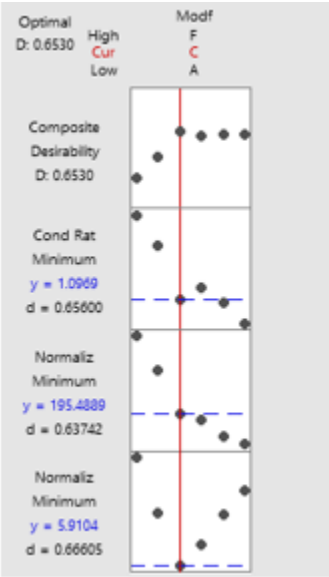

Fig. 15: Optimal Modification According to Drying Ratio, Drying Time and Energy Consumption

Conclusion and Recommendations

With these experimental studies conducted for the condenser drying machine, the drying air flow rate and heating power were kept constant, and the effects of the cooling air flow rate and the inlet temperature of the cooling air to the condenser on the essential outputs of the drying machine, namely drying rate, energy consumption, and drying time, have been examined.

In this experimental study, it has been observed that an increase in the cooling air flow rate and a decrease in the inlet temperature of the cooling air to the condenser have an impact on condensation and energy consumption. However, with the increase in the cooling load, it was observed that the temperature of the drying air leaving the condenser dropped significantly, leading to a prolonged duration of the heater being active, managed by an algorithm. The duration of the heater being active directly increased energy consumption. Among the conducted modifications, Modification C yielded the most optimum results. To further expand the studies, the air flow rate of the drying air, heating power, and the heating operation algorithm can be explored.

Increasing the number of tests can certainly lead to changes in average results. However, the trends in the results obtained through experimental studies are very clear. The flow rate and temperature of the cooling air significantly affect drying performance and energy consumption.

Thanks and Information Note

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BİR ELEKTRİK MOTORUNUN TİTREŞİMİNDEN PİEZOELEKTRİK ENERJİ HASADI İLE ELDE EDİLEN ENERJİNİN MODELLENMESİ*

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ÖZET

Enerjinin dünyada oldukça kritik seviyelerde ihtiyaç duyulduğu bu dönemde ortamda atıl olan titreşimin enerjiye dönüştürülme ve verim elde etme çalışması küresel bir önem arz etmektedir. Piezoelektrik enerji hasadının ortamdaki titreşimden elektrik enerji üretmesi; enerji kaybını azaltmaktadır. Bu çalışmada piezoelektrik enerji hasat ünitesi ile bir elektrik motoru üzerindeki titreşim piezoelektrik enerji hasadı ve hasatta enerji üretimini yükseltmek amacıyla çeşitli senaryolar üzerinden bir değerlendirme yapılmıştır. Elde edilen elektrik enerjisinin hangi durumlarda daha üst seviyelere çıkabileceği ve elektrik üretiminde kullanılacak olan piezo dönüştürücünün farklı ağırlıklar altında nasıl bir tepki göstereceği ve ne tür sonuçlar vereceğine dair senaryoları ortaya konulmuştur. Ağırlıklı ve ağırlıksız piezo dönüştürücü senaryoları Ansys Workbench paket programında çeşitli modlarda simule edilmiştir. Ansys Workbench paket programı aracılığıyla doğal frekansı bulmak için sonlu elemanlar ve modal analiz yöntemi uygulanmıştır. İlk olarak Piezo dönüştürücü ağırlıksız bir şekilde program içeriğinde bulunan modal analiz ve sonlu elemanlar metotu kullanılarak doğal çalışma frekansını deney ortamında kullanılan 50 Hz çalışma frekansına sahip olan motorun frekansına olabildiğince yakınlaştırmak için çalışmalar yapılmıştır. Sonrasında ise piezo dönüştürücü üzerine 0.17 gr ağırlıklı 4 mm çapa sahip olan 7000 kg/m³ yoğunluğa 0.24 poisson oranına sahip magnetler farklı adet ve yerleşim düzenleri ile yerleştirilmiştir. Program çözümünde her bir senaryonun en yüksek elektrik enerji çıktısı elde edeceği doğal frekans değerleri bulunarak bu frekans değerleri içinde üretilen elektrik değerleri ortaya konulmuştur ve irdelenmiştir. Bu durumun yanısıra piezoelektrik dönüştürücülerin hangi işlevlerde ve nasıl fayda sağlayacakları irdelenmiştir.

Anahtar Kelimeler: Modal analiz, Piezoelektrik enerji hasadı, Sonlu elemanlar analizi

ABSTRACT

In this period when energy is needed at very critical levels in the world, the study of converting the inert vibration in the environment into energy and obtaining efficiency is of global importance. Piezoelectric energy harvesting generates electrical energy from the vibration in the environment; reduces energy loss. In this study, piezoelectric energy harvesting unit and vibration on an electric motor were evaluated over various scenarios in order to increase the energy production in piezoelectric energy harvesting and harvesting. Scenarios have been put forward in which cases the electrical energy obtained can be increased to higher levels and how the piezo transducer to be used in electricity generation will react under different weights and what kind of results it will give. Weighted and unweighted piezo transducer scenarios were simulated in various modes in Ansys Workbench package program. Finite element and modal analysis method was applied to find the natural frequency through Ansys Workbench package program. Firstly, the piezo transducer was weightlessly simulated using the modal analysis and finite element method in the program to get the natural operating frequency as close as possible to the frequency of the motor with an operating frequency of 50 Hz used in the experimental environment. Afterwards, magnets with a weight of 0.17 g and a diameter of 4 mm with a density

of 7000 kg / m³ and a Poisson's ratio of 0.24 were placed on the piezo transducer with different numbers and layouts. In the program solution, the natural frequency values at which each scenario will obtain the highest electrical energy output are found and the electrical values produced within these frequency values are revealed and examined. In addition to this situation, the functions and benefits of piezoelectric converters have been analyzed.

Keywords: Modal analysis, Piezoelectric energy harvesting, Finite element analysis

Giriş

Bütün enerji kaynaklarından enerji üretilmesi için uygulanması gereken proseslere benzer olarak ortamda boşa giden enerji üretilebilecek kaynak olarak nitelendirdiğimiz titreşim de ortamdan ayırmak, toplamak için uygulanması gereken prosesler, çeşitli metotlar mevcuttur. Piezoelektrik dönüştürücülerden enerji hasadı, ya diğer elektronik devrelere güç sağlamak veya titreşimi sönümlemek için kullanılır (Lesieutre vd., 2004). Ottman vd. (2003) bir AC-DC tam doğrultma devresi önererek maksimum gücü kontrol etmek amacıyla bir pili verimlilikle şarj etmek için kullanıldı ve yaklaşık %74–88 oranında dolum elde edilmiştir. Toplanan gücü maksimize etmek amacıyla gelişmiş bir senkronize anahtarlama toplama sistemi (ESSH) önerilmiştir (Shen vd., 2011).

Çalışmada ortaya konulmak istenen amaç ve bu çalışmayı farklı kılan özellik hemen hemen herkesin kolayca temin edebileceği ekipman kullanımı ile bulunduğu ortamda değerlendirilmeyen titreşim enerjisinin farkındalığı ve bu enerjinin basit bir şekilde elektrik enerjisine dönüştürülebileceğini göstermektir. Bu bağlamda ortaya çıkan elektrik enerjisinin büyüklüğü ne oranda fayda sağlanabileceği nasıl geliştirilebileceği konusunda çalışmalar yapılmış olup günümüz enerji koşulları içerisinde çalışan bir sistem içerisinde yararlanabileceği gösterilmiştir.

Bu çalışmada herkesin kolayca temin edilebileceği ekipmanlarla oluşturabileceği enerji hasat ünitesi ile bir elektrik motoru üzerinde oluşan titreşimden piezoelektrik enerji hasadı yapılmıştır. Elde edilen elektrik enerjisinin hangi durumlarda daha üst seviyelere çıkabileceği ve elektrik üretiminde kullanılacak olan piezo dönüştürücünün ağırlık altında nasıl bir tepki göstereceği ve ne tür sonuçlar vereceğine dair senaryoları ortaya koymak amaçlanmaktadır. Ağırlıklı ve ağırlıksız piezo dönüştürücü senaryoları yine Ansys programında 6 ayrı modda (titreşim esnasında frekans değerlerinde ortaya çıkan geometri) simule edilmiştir. Program çözümünde her bir senaryonun en yüksek elektrik enerji çıktısı elde edeceği doğal frekans değerleri bulunmuş olup bunun yanı sıra bu frekans değerleri içinde malzemedeki elastik gerilim sonuçları ortaya konularak karşılaştırılmıştır. Bu karşılaştırmanın nedeni ise piezo elektrik bir malzemede elastik gerilim değeri ne denli yüksek olursa elde edilecek enerji çıktı değerinin de o ölçüde yüksek olacağının gösterilmesidir. 50 Hz sabit frekansta çalışan deney düzeneğinde elektrik motoruna bağlanan piezo dönüştürücünün en yüksek verimlilikte ve düzeyde elektrik elde etmesi için elektrik motoru ile rezonans durumunda olması teorik olarak bilinen bir gerçektir. Bu bağlamda ansys programında 0.17 gr ağırlık ve 4 mm çapa sahip olan magnetlerden kullanılan piezo dönüştürücünün elektrik motoruyla rezonans oluşturması amacıyla kaç adet konulması üzerine de bir çalışma yapılmıştır. Bütün bu çalışmalar programda modellendikten sonra her bir senaryonun doğal titreşim frekansı bulunmuş ve deney ortamında elektrik enerjisi elde edilmesi amaçlanmıştır. Deney laboratuvarında 50 Hz frekans değerine sahip bir elektrik motoru üzerine eliptik şeklide 50mm çapa sahip 35 mm'lik orta kısmı PZT-5A(Piezo Seramik), geri kalan kısmı pirinçten oluşan bir piezo dönüştürücü, malzemenin orta kısmından 1 mm çapa 7850kg/m³ yoğunluğa sahip yapı çeliği ile elektrik motoruna bağlanmıştır. Piezoelektrik enerji hasadı ünitesi tasarlanmış elektrik motorunun çalışmaya başlamasıyla birlikte üretilecek olan elektriğin AC (Altenatif Akım) olduğu görülmüş bu akımın DC (Doğru Akım) haline getirmek amacıyla tam doğrultma devresi hazırlanmış, tam doğrultma devresinde sırasıyla dört adet diyot, üç adet köprü diyot, bir adet 2200 mikro farad kapasitör ve sırasıyla değiştirilmek üzere 56, 110, 220, 330 kg ohm'luk dirençler bağlanmıştır. Çıkan elektrik voltaj değerleri osiloskop yardımıyla okunmuş olup güç değeri V^2/R formülünden yararlanılarak bulunmuş olup direnç, üretilen voltaj ve güç değerleri gösterilmiştir.

Materyal ve Yöntem

Bu çalışmanın yönteminin temelinde Piezoelektrik enerji hasadı, sonlu elemanlar analizi ve modal analiz ve nümerik analiz kullanılmış olup deneysel ortamda uygulaması yapılmıştır.Bu çalışmada piezoelektrik enerji hasat yöntemi uygulanmış olup bu yöntemin diğer yöntemlere karşı tercih edilmesinde uygulayacağımız

sisteme entegresinin daha kolay olması diğer yöntemlere kıyasla daha yüksek enerji verimi ve birim enerji yoğunluğuna sahip olması durumu ön plana çıkmaktadır.Piezoelektrik malzemeler basınç, titreşim veya kuvvet tahriki sonucu meydana gelen mekanik enerjiyi elektrik enerjisine dönüştürürler. Bu malzemeler titreşimle veya hareketle karşılaştıklarında, elektriksel bir yük üretme kabiliyetine sahiptir. Piezoelektrik malzemeler ile güç üretilmesi konusunda literatürde pek çok uygulama mevcuttur (Cavallier vd., 2005; Minazara vd.,2008; Kim vd., 2008; Makki ve N., Pop-Iliev, 2011)

Sonlu elemanlar analizi ile gereksinim duyulan işleme yönteminin simülasyonları oluşturularak kesme parametrelerinin işleme çıktıları (ilerleme kuvveti, moment, sıcaklık vs.) üzerindeki etkileri bilinebilmektedir (Günay vd., 2018). Bunun sonucu olarak, deneysel yöntemle ulaşılması zor olan dataların tespit edilmesine ve işleme tekniği üzerinde bir fikir oluşturulmasına imkân vermektedir. (Su vd., 2015).

Bu çalışmada kullanılan nümerik analiz formülleri Piezoelektririğin kurucu(ana) denklemlerinden faydalanılarak yapılmıştır. Bu denklemler Ansys Workbench paket programında kullandığımız PZT-5A malzemesinin sonlu elemenlar çözüm yönteminde paket program tarafından atanmış düğüm materyal bölümünün ana denklemleridir. (URL1)

Sonlu elemanlar analizine ek olarakmodal analizin yapılma sebebi ise literatürde şu şekilde açıklanmıştır. Titreşen bir makina veya makine parçasının sonlu elemanlar modeli üzerinden titreşim analizinin gerçekleştirilmesi, ortaya çıkması muhtemel modelleme hataları nedeni ile genellikle birincil bir çözüm olarak düşünülmez. Kurulan modelin, deneysel modal analiz yöntemleri ile kabul edilebilir bir düzeyde hassasiyete sahip olduğu belirlendikten sonra, gerekli analiz ve iyileştirmelerin sonlu eleman modelleri üzerinden yapılması daha uygun olabilir (Dooms vd., 2006).

Bu çalışmada PZT-5A malzemesinin seçilme sebebi deney ortamında kullanılan elektrik motorunun sabit 50Hz frekansta çalışmasından kaynaklı optimum verimi elde edebilecek piezoelektrik malzeme kullanılmasının tercih edilmesi ve bu tercih 0-200 Hz frekans aralığında daha yüksek enerji yoğunluğuna sahip olan 0.9Pb(Zr0.56Ti0.44)O3– 0.1Pb[(Zn0.8/3Ni0.2/3) Nb2/3]O3 + 2 mol% MnO2 (PZTZNN) ve 0.8[Pb(Zr0.52Ti0.48) O3]–0.2[Pb(Zn1/3Nb2/3)O3] (PZT/PZN) sentezlenerek geleneksel seramik malzemelere kıyasla rezonans değerlerine daha kolay ulaşmasıdır. Bu noktada ortaya konan çalışmalar şunu göstermiştir ki sentezlenen bu yeni malzemenin üretim gücü (d*g) diğer malzemelere göre artmıştır (Bedekar vd., 2010). Bu bağlamda kullanılan d değeri piezoelektrik gerilim sabiti g değeri ise piezoelektrik voltaj sabitidir. Bu değer ise seçtiğimiz PZT-5A malzemesinde d33 değeri 430 10-12C/N g33 değeri ise 25 (10-3Vm/N) değerindedir [URL 2].

Araştırma ve Bulgular

Piezoelektirik Dönüştürücünün Modellemesi Üzerinden Modal ve Sonlu Elemanlar Analizi

Bu bölümde ağırlıksız piezo dönüştürücü ve piezo dönüştürücünün üzerine 0.17 gr ağırlığındaki çelik magnetlerin farklı sayı ve geometrik dizilimle yerleştirilmesiyle oluşan beş farklı senaryo ANSYS Workbench (ANSYS Inc.Canonsburg, PA) programı aracılığı ile modellenmiştir.

Tablo 1. Modellenen beş farklı senaryo ve etkenler

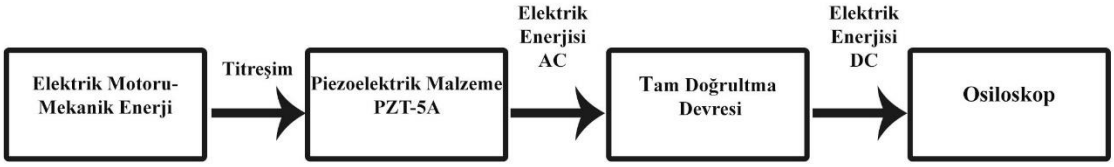
Etkenler	Senaryo 1	Senaryo 2	Senaryo 3	Senaryo 4	Senaryo 5
Ağırlık sayısı	-	4 magnet (0.68 gr)	6 magnet (0.68 gr)	8 magnet (1.36 gr)	12 magnetli (2.04 gr)
Ağırlık dizilimi	-	90 derecelik açılarla	60 derecelik açılarla	90 derecelik açılarla	60 derecelik açılarla

Senaryolarda Tablo 1'de belirtildiği gibi sadece magnet sayı ve diziliminde farklılar vardır. Modellenen piezo dönüştürücü ve magnetlerin malzeme ve özellikleri aynı tutulmuştur.

Tablo 2. Modellemede kullanılan piezo dönüştürücünün içerdiği malzemelerin mekanik özellikleri

Özellik	Çelik	Pirinç	PZT-5A	Magnet
Young Modülü (GPa)	200	117	66	0.008
Poisson Oranı	0,30000	0,34000	0,34000	0,24000
Yoğunluk (kg/m³)	7850,0	8450,0	7800,0	7000,0

Senaryodaki enerji akış diyagramı Şekil 1'de gösterilmiştir.



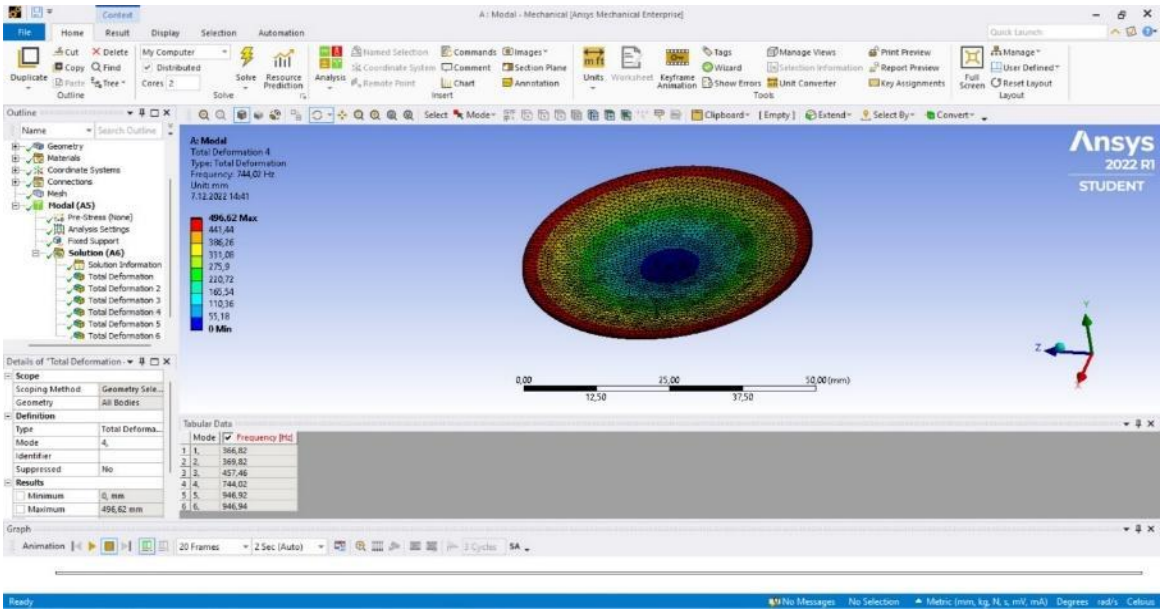
Şekil 1. Enerji akış diyagramı

Senaryo 1: Ağırlıksız Piezo Dönüştürücü Modeli

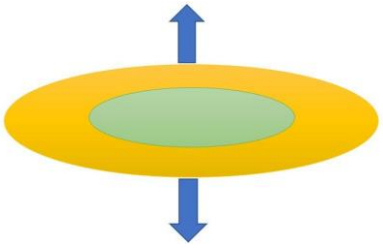
Bu modelde 50 mm çapa sahip pirinç plakanın merkez bölgesinde çapı 35 mm olan PZT-5A malzemesi bulunmaktadır ve ANYS Workbench programında bu ölçüler özelinde modellenmiştir.

Ağırlıksız Senaryo Total Deformasyon Modları

Sonlu elemanlar analizi uyarınca gerekli elementler ansys programında piezo dönüştürücüye atanmış ve sonrasında ise doğal frekans değerlerini bulmak amacıyla çözüm işlemi başlatılmıştır. Ağırlıksız dönüştürücü üzerinde modal analiz yapılmış toplam deformasyon 6 modda araştırılmıştır. Bu çalışma kapsamında piezo dönüştürücünün istenilen salınım hareketini ve istenilen elastik gerilimi yapmış olduğu mod gösterilmiştir (Şekil 2).



Şekil 2. Piezo dönüştürücü total deformasyon Mod 4



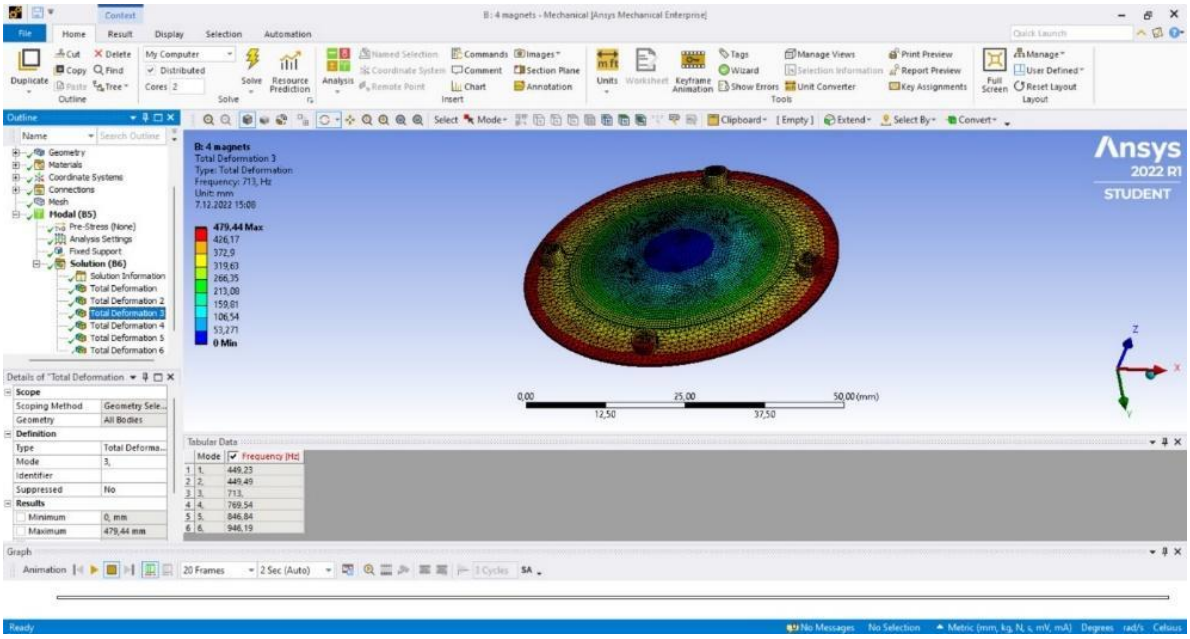
Şekil 3. Ağırlıksız piezo dönüştürücü salınım hareketi Mod 4

Yapılan mod 4 değerledirmesinde piezo dönüştürücü 744,02 Hz te titreştirilmiş ve istenilen sonuç elde edilmiştir. Piezo dönüştürücü salınım şekli Şekil 3'de gösterilmiştir.

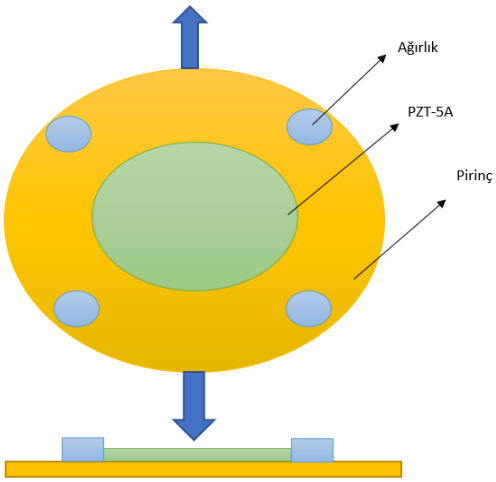
Senaryo 2: 4 Adet Magnet 0,68 Gr Ağırlıklı Piezo Dönüştürücü Senaryo Modeli

Bu modelde eliptik şekilli 50 mm çapa sahip çapı 35 mm olan orta kısmı PZT-5A malzemesinde geri kalan kısmı ise pirinç malzemesinden olan piezo dönüştürücü üzerine 90°'lik açısal aralıklarla 0,17 gr ağırlığa sahip 4 adet magnet yerleştirilmiş ve ANSYS Workbench programında modellenmiştir.

Total deformasyon 4 magnet 0,68 gr ağırlıklı Modları



Şekil 4. ANSYS Workbench programında deneyde dört magnetli kullanılan piezo dönüştürücü mod 3



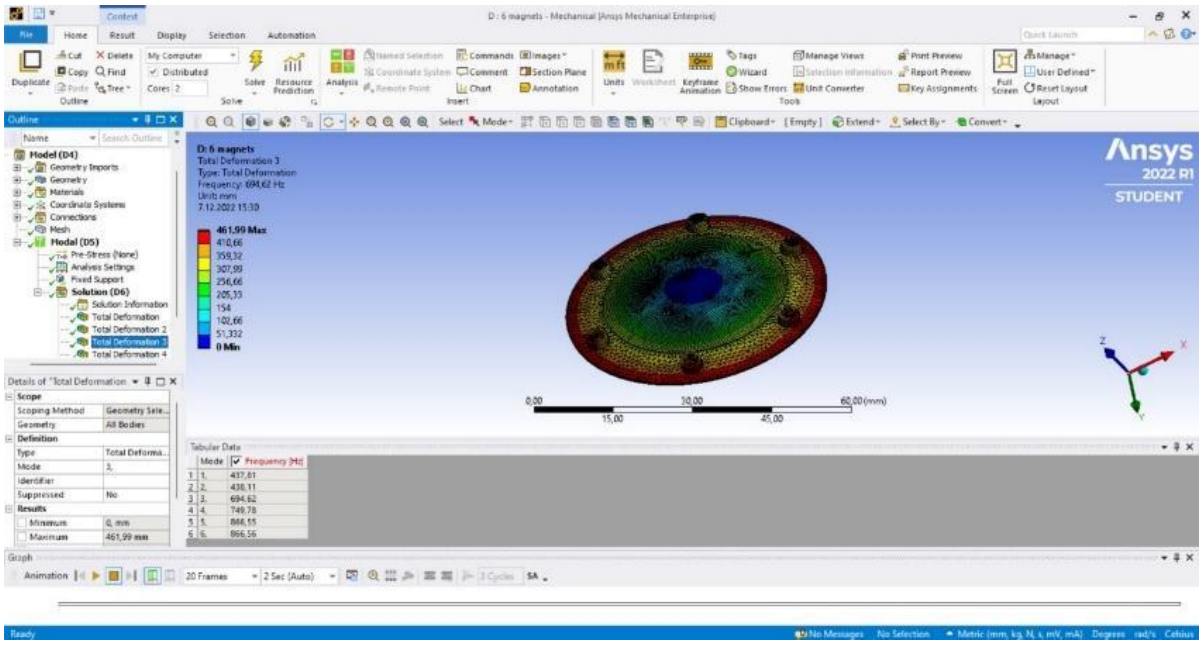
Şekil 5. Dört magnet 0,68 gr ağırlıkta piezo dönüştürücü salınım hareketi mod 3

Yapılan mod 3 analizinde piezo dönüştürücü 713 Hz' de titreştirilmiş ve istenilen sonuç elde edilmiştir. Piezo dönüştürücü salınım şekli Şekil 5'te gösterilmiştir.

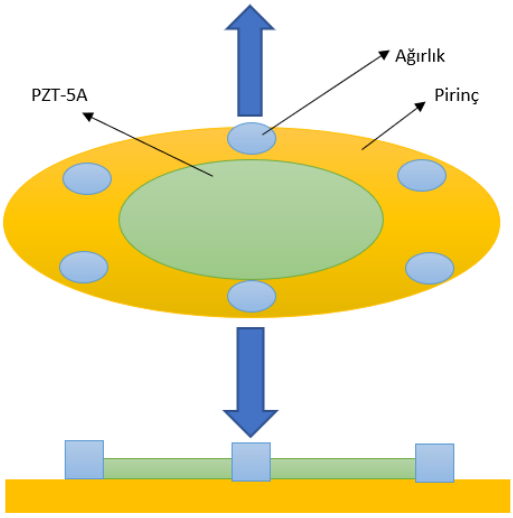
Senaryo 3: 6 Adet Magnet 1,02 Gr Ağırlıklı Piezo Dönüştürücü Senaryo Modeli

Bu modelde eliptik şekilli 50 mm çapa sahip çapı 35 mm olan orta kısmı PZT-5A malzemesinden geri kalan kısmı ise pirinç malzemesinden olan piezo dönüştürücü üzerine 60°lik açısal aralıklarla 0,17 gr ağırlığa sahip 6 adet magnet yerleştirilmiş ve ANSYS Workbench programında modellenmiştir.

Total deformasyon 6 magnet 1,02 gr ağırlıklı Modları:



Şekil 6. ANSYS Workbench programında deneyde altı magnetli kullanılan piezo dönüştürücü mod 3



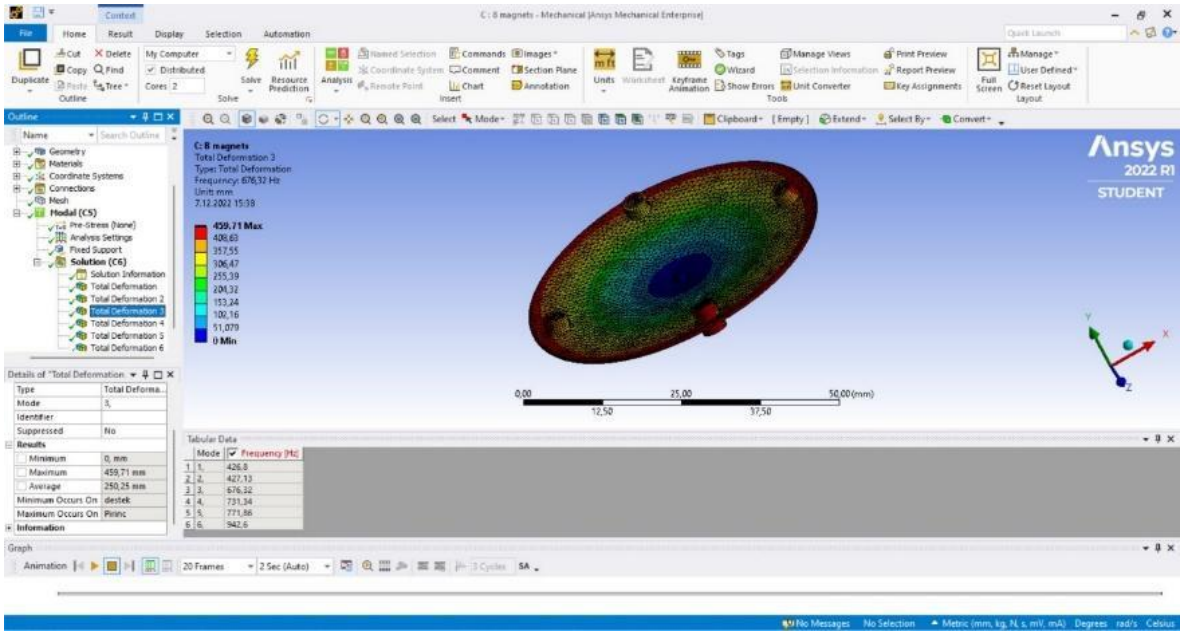
Şekil 7. Altı magnet 1,02 gr ağırlıkta piezo dönüştürücü salınım hareketi mod 3

Yapılan mod 3 analizinde piezo dönüştürücü 694,62 Hz te titreştirilmiş ve istenilen sonuç elde edilmiştir. Piezo dönüştürücü salınım şekli Şekil 7'de gösterilmiştir.

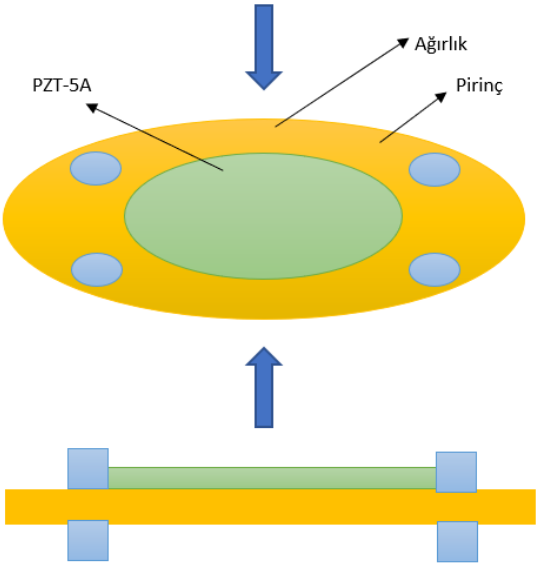
Senaryo 4: 8 Adet Magnet 1,36 Gr Ağırlıklı Piezo Dönüştürücü Senaryo Modeli

Bu modelde eliptik şekilli 50 mm çapa sahip çapı 35 mm olan orta kısmı PZT-5A malzemesinden geri kalan kısmı ise pirinç malzemesinden olan piezo dönüştürücü üzerine 90°lik açısal aralıklarla 0,17 gr ağırlığa sahip 8 adet magnet 4 tanesi malzeme alt tarafında 4 tanesi malzeme üst trafında olmak kaydıyla piezo dönüştürücünün alt ve üst yüzeylerine yerleştirilmiş ve ANSYS Workbench programında modellenmiştir.

Total deformasyon 8 magnet 1,36 gr ağırlıklı Modları



Şekil 8. ANSYS Workbench programında deneyde sekiz magnetli kullanılan piezo dönüştürücü mod 3



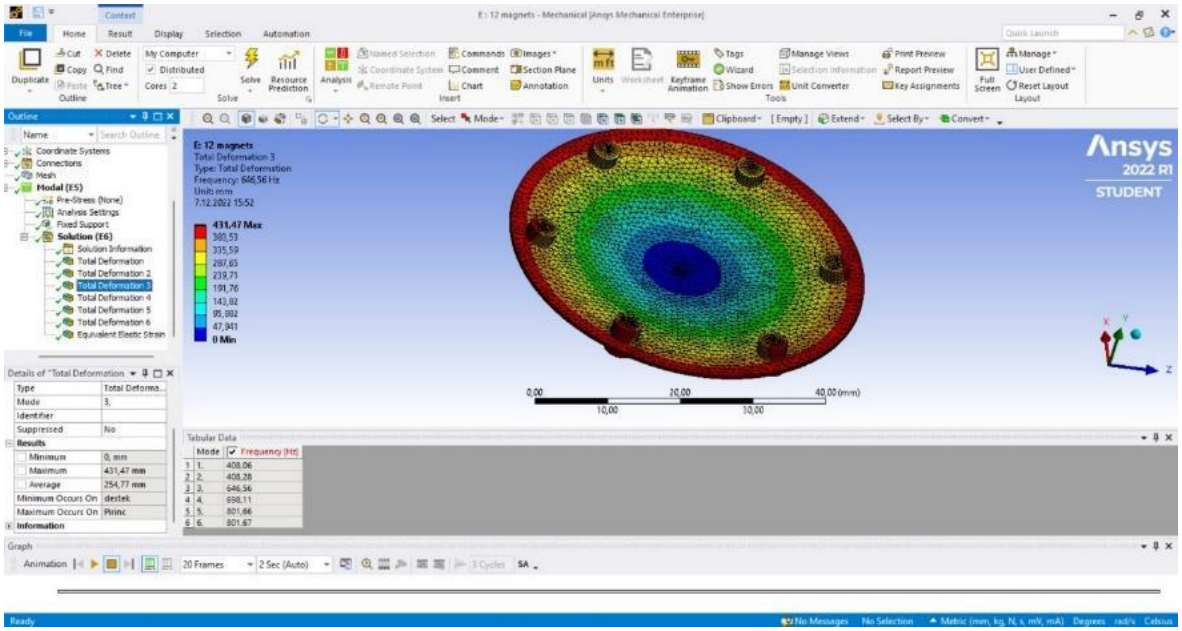
Şekil 9. Sekiz magnet 1,36 gr ağırlıkta piezo dönüştürücü salınım hareketi mod 3

Yapılan mod 3 analizinde piezo dönüştürücü 676,32 Hz te titreştirilmiş ve istenilen sonuç elde edilmiştir. Piezo dönüştürücü salınım şekli Şekil 9'da gösterilmiştir.

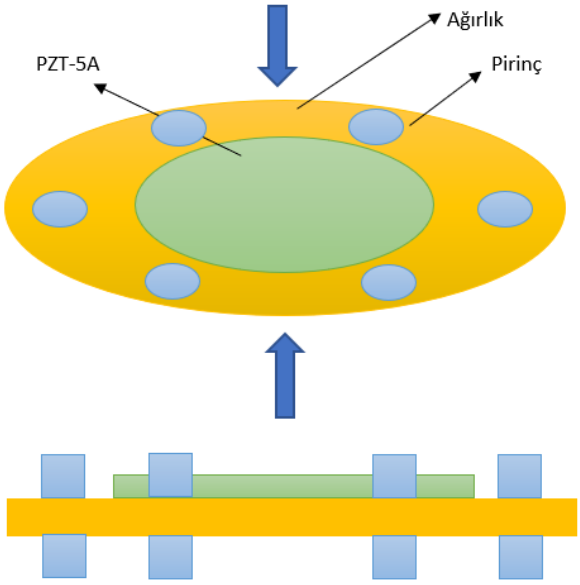
Senaryo 5: 12 Adet Magnet 2,04 Gr Ağırlıklı Piezo Dönüştürücü Senaryo Modeli

Bu modelde eliptik şekilli 50 mm çapa sahip çapı 35 mm olan orta kısmı PZT-5A malzemesinden geri kalan kısmı ise pirinç malzemesinden olan piezo dönüştürücü üzerine 60°lik açısal aralıklarla 0,17 gr ağırlığa sahip 12 adet magnet 6 tanesi malzeme alt tarafında 6 tanesi malzeme üst tarafında olmak kaydıyla piezo dönüştürücünün alt ve üst yüzeylerine yerleştirilmiş ve ANSYS Workbench programında modellenmiştir.

Total deformasyon 12 magnet 2,04 gr ağırlıklı Modları



Şekil 10. ANSYS Workbench programında deneyde 12 magnetli kullanılan piezo dönüştürücü mod 3

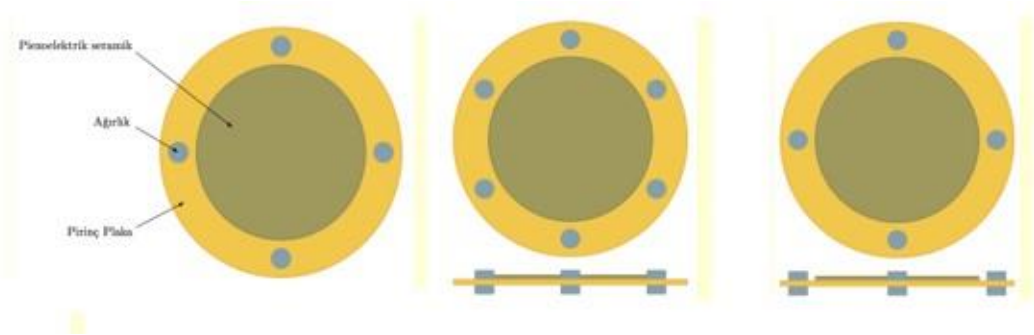


Şekil 11. 12 magnet 2,04 gr ağırlıkta piezo dönüştürücü salınım hareketi mod 3

Yapılan mod 3 analizinde piezo dönüştürücü 646,56 Hz te titreştirilmiş ve istenilen sonuç elde edilmiştir. Piezo dönüştürücü salınım şekli Şekil 11'de gösterilmiştir.

Deneysel Uygulama

Oluşturulan deney düzeneği, elde edilecek enerji miktarını azami düzeye çıkarmak düşüncesiyle tasarlanmıştır. Kullanılan piezoelektrik dönüştürücünün doğal frekansını, üzerine bağlandığı motorun titreşim frekansına mümkün olduğunca yaklaştırabilmek amacıyla dönüştürücünün üzerine çeşitli konfigürasyonlarda ağırlıklar bağlanmıştır. (Şekil 12).

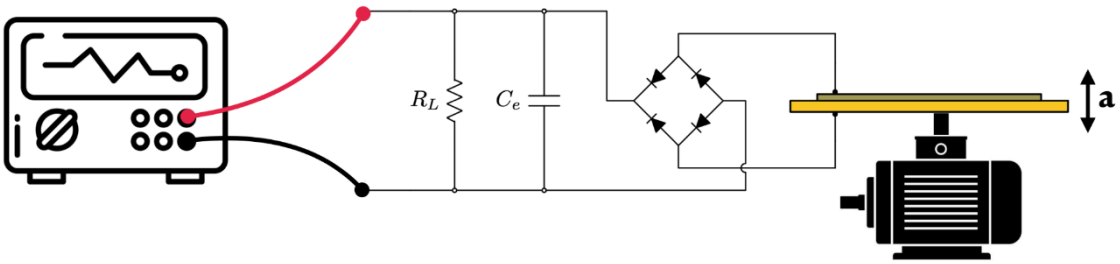


Şekil 12. Deneylerde kullanılan dönüştürücü ve farklı ağırlık konfigürasyonları

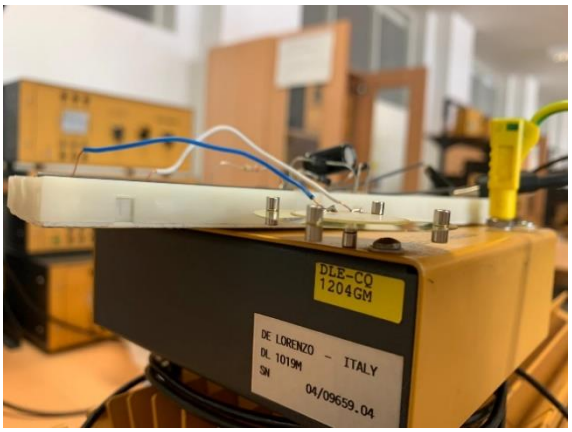
Ağırlıkların konfigürasyonu ve sayısı değiştikçe sistemden elde edilen enerjinin nasıl değişeceği ve elektriksel empedans değişiminin elde edilen enerjiye etkisi gibi etkenleri belirlemek için deneysel çalışma düzeneğinde ağırlık ilavesinin yanı sıra enerji hasatı uygulamalarında kullanılan türde bir de elektronik devre ilave edilmiştir.

Elektrik motoruna bağlanan piezo dönüştürücüin ürettiği elektrik akımı AC (Alternatif Akım) olduğu için bu noktada alternatif akımı DC (Doğru Akım)'ye dönüştürebilmek için tam doğrultma devresi adı verilen bir araç kullanılması gerekliliği doğmuştur. Tam doğrultma devresi AC akımı DC akıma çeviren bir araç olmakla birlikte devreye eklenebilen çeşitli direnç değerleri ile birlikte maksimum elektrik eldesi konusunda da işlev görebilmektedir. Deney düzeneğinde kullanılan tam doğrultma devresi aşağıdaki şekildeki gibi tasarlanmıştır.

Oluşturulan deney düzeneği Şekil 13'te verilmiştir. Piezoelektrik dönüştürücü (Şekil 14.), elektrik motorunun üzerine sabitlenmiş ve motorun çalışmasıyla (Şekil 14) oluşan titreşim sonucu dönüştürücünün ürettiği enerji sonucu oluşan voltaj tam doğrultucu köprü ve arkasına eklenen kondansatör yardımıyla doğrultulmuştur (Şekil 16-17) ve voltajın ölçümüne izin verecek şekilde bir elektriksel direnç üzerinden geçirilmiştir. Voltaj değeri bir dijital osiloskop (Şekil 18) yardımıyla ölçülmüş ve Vp-p (tepeden tepeye voltaj- peak to peak voltage) olarak kaydedilmiştir.

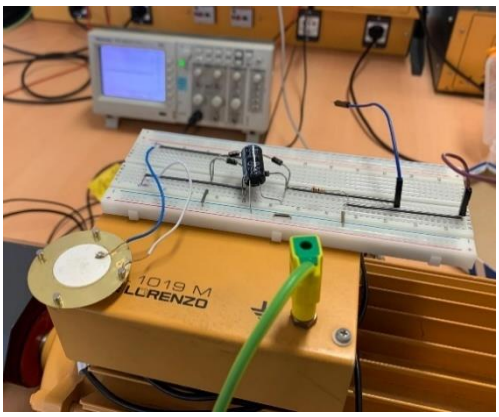


Şekil 13. Deney düzeneği

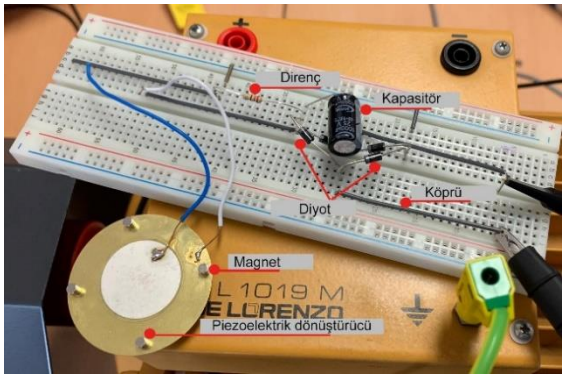


Şekil 14. De Lorenzo DL 1019M Elektrik Motoruna sabitlemiş ağırlıklı piezo dönüştürücü

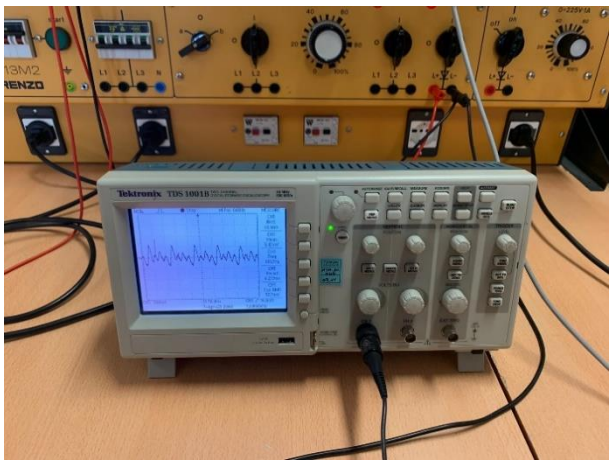
Şekil 15. De Lorenzo DL 1019M Elektrik Motoru



Şekil 16. Tam doğrultma devresi ve Piezoelektrik dönüştürücü



Şekil 17. Tam doğrultma devresi birleşenleri



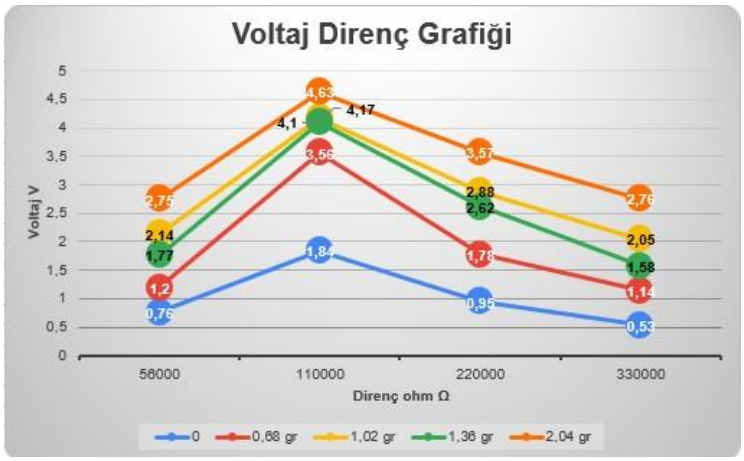
Şekil 18. Tektronix TDS 1001B Dijital Osiloskop

Elde Edilen Sonuçlar

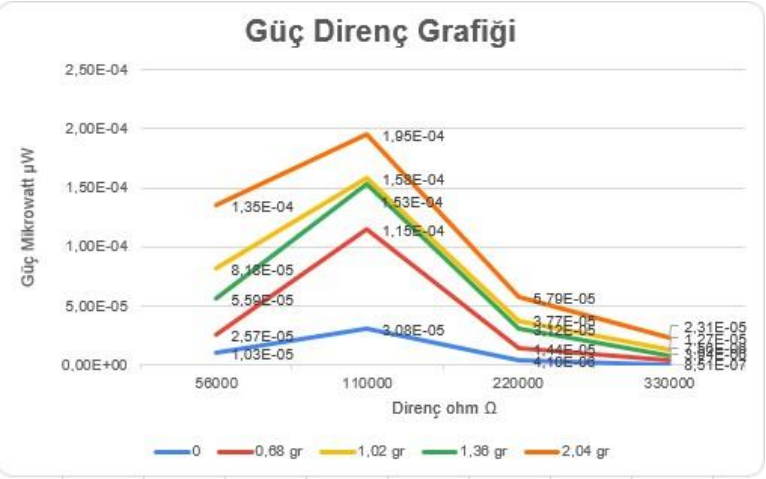
Deney sonucu elde edilen değerler tablo ve grafik oluşturularak gösterilmiştir.

Tablo 3. Ağırlıklı ve ağırlıksız piezo dönüştürücülerin ürettiği voltaj ve güç değerleri

Rezonans Frekansı (Hz)	744.02 Hz	713 Hz	694.62 Hz	676.32 Hz	646.56 Hz	
DİRENÇ(Ω)/MAGNET AĞIRLIĞI(gr)	0	0,68 gr	1,02 gr	1,36 gr	2,04 gr	
56000 Ω	0,76	1,2	2,14	1,77	2,75	Voltaj (V)
110000 Ω	1,84	3,56	4,17	4,1	4,63	
220000 Ω	0,95	1,78	2,88	2,62	3,57	
330000 Ω	0,53	1,14	2,05	1,58	2,76	
Bulunan voltaj değerleri sonucunda güç hesaplaması $P=V^2/R$ formülüzasyonu kullanılarak hesaplanmış ve tabloda verilmiştir.						
Rezonans Frekansı (Hz)	744.02 Hz	713 Hz	694.62 Hz	676.32 Hz	646.56 Hz	
DİRENÇ(Ω)/MAGNET AĞIRLIĞI(gr)	0	0,68 gr	1,02 gr	1,36 gr	2,04 gr	
56000 Ω	1,03E-05	2,57E-05	8,18E-05	5,59E-05	1,35E-04	Güç (µWatt)
110000 Ω	3,08E-05	1,15E-04	1,58E-04	1,53E-04	1,95E-04	
220000 Ω	4,10E-06	1,44E-05	3,77E-05	3,12E-05	5,79E-05	
330000 Ω	8,51E-07	3,94E-06	1,27E-05	7,56E-06	2,31E-05	



Şekil 19. Ağırlıksız ve ağırlıklı piezo dönüştürücülerin dirençler karşısında voltaj üretim karşılaştırmaları



Şekil 20. Ağırlıksız ve ağırlıklı piezo dönüştürücülerin dirençler karşısında güç üretim karşılaştırmaları

Tam doğrultma devresinde değiştirilen direnç değerlerine göre 56k Ω değerinden 110 k Ω değerine doğru yükselme trendi görülen dönüştürücü 110 k Ω değerinde pik seviyesini yakaladıktan sonra ürettiği enerji değerlerinde düşüş göstermiştir.

Sonuçlar ve Değerlendirme

ANSYS programında yapılan analizler sonucu piezo dönüştürücü üzerindeki ağırlıkların artmasıyla birlikte dönüştürücünün doğal frekansının azaldığı tespit edilmiştir.,

Laboratuvar ortamında elde edilen sonuçlar irdelendiğinde üzerine 6 magnet yerleştirilen piezo dönüştürücü ile 8 magnet yerleştirilen piezo dönüştürücü arasında elde edilen voltaj ve güç değerlerinde ağırlıkların artış oranı ile ters orantılı bir sonuç elde edilmiştir.110 k Ω direnç değerinde aralarında 60 °'lik açılarla yerleştirilen 6 magnetli piezı dönüştürücü 4,17 voltluk elektrik enerjisi üretirken, plakanın alt ve üst yüzeylerine 90°'lik açılarla yerleştirilmiş olan 8 magnetli piezo dönüştürücü 4,1 voltluk elektrik enerjisi üretmiştir. Ağırlıkların artmasıyla birlikte artış gösteren elektrik enerji eldesi ile ters orantlı olan bu durum ağırlıkların geometrik dizilimiyle ilişkilendirilmiştir.Plaka yüzeyine yerleştirilen 60° açısal aralıklarla yerleştirilen magnetler dönüştürücü elektrik eldesinde daha verimli olmuşlardır.

Piezoelektrik dönüştürücü titreşim oluşturan herhangi bir sistem üzerinde başka bir enerji kaynağına ihtiyaç duymadan kullanılabilmekle birlikte üretmiş olduğu elektrik enerjisi ise kablosuz sensörler, küçük teçhizatlar olmak üzere kullanılabilir. Bunun yanı sıra sürekli çalışmakta olan makinelerde ortaya çıkan titreşim hem makineye hemde gürültü olarak çevreye zarar vermektedir. Makine ve elemanlarının çalışma ömrünü olumsuz etkileyen titreşim makine parçalarının da yorulma ömürlerini kısaltır. Bu noktada makine teçhizat sisteminin üzerine konumlandırılacak piezoelektrik enerji hasadı sistemi makine üzerindeki titreşimi sönümleyerek enerji eldesinin yanı sıra ortamdaki gürültüyü azaltmakla birlikte makine parçalarının çalışmasındaki olumsuz etkileri azaltacağı gibi yaşlanma ömürlerine de olumlu etki edebilir.

Makinelerin yoğun bir şekilde ve ara vermeksizin sürekli çalıştığı bütün sektörlerde makinalar için en önemli etkenlerden birisi de sürekli ve aynı verimde çalışabilmesidir. Bu nedenle gerek periyodik bakım gerekse düzenli takip ile birlikte üretimin aksamaması için yapılan bakım onarım çalışmalarındaki en önemli nokta makine ya da ekipmanlarının arıza durumuna geçmeden önce tespit edilmesi ve üretimde aksaklık yaratmadan önleminin alınabilmesidir. Bu kapsamda enerjisini ortamdaki değerlendirilmeyen titreşimden alıp başka bir enerjiye ihtiyaç duymadan çalışabilen piezolektrik malzemeden üretilmiş bir sistem bir taraftan bağlı olduğu makinedeki frekans değerlerini nesnelerin interneti kapsamında iletmede kullanılabilirken bir taraftan da kendi ürettiği elektrik enerjisi ile çevredeki küçük teçhizatlara elektrik enerjisi sağlayabilir.

Teşekkürler ve Bilgilendirme Notu

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TURBOJET MOTORLARDA YANMA ODASI SİSTEMİ İÇİN ISI KALKANI TASARIM VE ANALİZİ

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ÖZET

Günümüzde savunma sanayisinde havacılık sektörü, beraberinde kritik teknolojileri barındıran, ülkemizde ve dünyada önemli bir yere sahip bir sektördür. Hava araçları için gerekli olan itkiyi üreten sistemlerden biri olan turbojet motorların itkiyi üretirken harcadığı yakıt enerjisi ile yüksek sıcaklıklar açığa çıkmaktadır. Bir arada uyum içinde çalışması gereken sistemlerin maruz kaldığı sıcaklıkların belirlenmesi ve önlem alınması için termal analiz yöntemlerinin gözden geçirilmesi ve gerekli bölgelerde termal yalıtım uygulamalarının yapılması sistemin güvenliği ve ömrü açısından kritiktir. Turbojet motorlarda yaygın olarak kullanılan termal yalıtım uygulamalarından biri de ısı kalkanı uygulamasıdır.

Bu bildiride, savunma sanayisindeki önemli yeri olan turbojet motorlarda ısı kalkanı tasarımının gereksinimlerinin belirlenmesi ve bu gereksinimlere uygun bir tasarım çalışmasından bahsedilecektir. Çalışma kapsamında yanma odası gövdede kullanılabilecek ısı kalkanının tasarım adımları belirlenmiş, tasarlanan ısı kalkanının analizleri gerçekleştirilmiştir.

Tasarım çalışmasının ilk aşaması turbojet motorda ısı kalkanının maruz kalacağı termal yükler için kullanılacak teorinin incelenmesi ile denklemlerin türetilmesidir. İlgili denklemler, turbojet motor çalışma prensibi gereği kullandığı yüksek sıcaklıktaki hava-yakıt karışımı ile iletim, taşınım ve ışıma gibi ısı transfer mekanizmalarının bir arada kullanılması ile termal direnç ve enerji dengesi denklemleri türetilmiştir sistem üzerindeki etkisi incelenmiştir.

Çalışmanın ikinci aşamasında ısı kalkanı üretimi için kullanılacak yalıtım malzeme seçilimi yapılmıştır. Yalıtım malzemesi seçilirken sektörde kullanılan uygulamalar incelenmiş olup seçilen 2 ürününün yalıtım performansı karşılaştırması için test faaliyeti yürütülmüştür. Kullanılacak yalıtım malzemesi belirlendikten sonra yalıtımı örten malzeme seçimi yapılmıştır.

Tasarım çalışmasının sonraki aşamasında dikkat edilmesi gereken hususlardan bahsedilmiştir. Tasarım geometrisi belirlendikten sonra CAD model oluşturulmuştur. Analiz programı kullanılarak örnek olarak girilen sıcaklık, akışkan hızı, ısı kalkanı çapı gibi sınır koşulları ile 2-Boyutlu ısı transferi uygulanmıştır. Farklı kalınlıklardaki yalıtım uygulamalarıyla elde edilecek sıcaklıklar ortaya çıkarılmıştır.

Son olarak elde edilen bulguların değerlendirilmesi, ısı kalkanı tasarım, analiz doğrulamasına yönelik uygulanması gereken yöntemler ile çalışmanın ileriye dönük planlarından bahsedilerek tamamlanmıştır.

Anahtar Kelimeler: Tubojet motor, ısı transferi, ısı kalkanı

ABSTRACT

In today's defense industry, the aviation sector is a significant field that encompasses critical technologies, holding a prominent position both in our country and worldwide. Turbojet engines, which are one of the systems responsible for generating the thrust required for aircraft, release high temperatures as a result of the fuel energy expended during thrust production. Determining the temperatures to which systems that must work in harmony are exposed and taking measures to prevent them is crucial for the safety and lifespan of the system. One commonly used thermal insulation application in turbojet engines is the implementation of a heat shield.

This paper discusses the determination of the requirements for heat shield design in turbojet engines, emphasizing its crucial role in the defense industry, and describes a design study that meets these requirements. The design steps for a heat shield that can be used in the combustion chamber of the engine are identified, and analyses of the designed heat shield are carried out.

The first stage of the design study involves examining the theory to be used for the thermal loads that the heat shield in the turbojet engine will be subjected to and deriving equations. The relevant equations are derived based on the principles of the turbojet engine, which involves the simultaneous use of heat transfer mechanisms such as conduction, convection, and radiation with the high-temperature air-fuel mixture used by the engine. The thermal resistance and energy balance equations are derived, and their impact on the system is examined.

In the second stage of the study, the selection of insulation material for heat shield production is discussed. The insulation material is chosen by examining applications used in the industry, and a test activity is conducted to compare the insulation performance of the selected materials. Once the insulation material is determined, the material covering the insulation is also chosen.

The next stage of study discusses important considerations after determining the design geometry. After defining the design geometry, a CAD model is created. Using an analysis program, two-dimensional heat transfer is applied with boundary conditions. Temperatures resulting from insulation applications of different thicknesses are revealed.

Finally, the paper concludes by evaluating the findings, discussing methods for the heat shield design and analysis verification, and outlining future plans for the study.

Keywords: Turbojet Engine, heat transfer, heat shield

GİRİŞ

Turbojet motorlar hava araçlarının ve roketlerin itki sistemlerinde yaygın olarak kullanılmaktadır. Motorların entegre edildiği platformların emniyetli bir şekilde görev profili sağlayabilmesinin bir unsuru da olası termal yüklerin belirlenip sıcak bölgeler için güvenli bir şekilde yalıtım sağlayacak komponentlerin tasarım ve analizi, ciddi mühendislik çalışmaları gerekmektedir.

İçten yanmalı motorların bir türü olan turbo jet motorlarda yakıt enerjisi, mekanik enerji ve itkiye çevrilerek kullanıldığı hava aracı platformuna ihtiyacı olan itkiyi sağlamakla görevlidir. Çalışma prensibi gereği, atmosferden çekilen hava sıkıştırılarak basıncı arttırılır. Basıncı artan hava, yakıt karışımı ile beraber yanarak yüksek enerjili gaz, türbini döndürerek faydalı işe dönüşür. Türbin enerjisini şafta ve kompresöre aktararak çevrim devam eder. Türbinden geçen yüksek enerjili gaz nozuldan dışarı atılarak itki oluşturulur.

Yanma sonucu oluşan yakıt hava karışımı, etkileşimde bulunduğu komponentlerinin sıcaklığı dramatik şekilde arttırarak türbin, rulman gibi döner elemanlarının çalışma ömrüne doğrudan etki etmesiyle beraber, yüksek basınç kompresör kademesi (kısaca, HPC) ve yüksek basınç türbin kademelerinde (Kısaca, HPT) termal dayanımı arttırmak ve ömrü uzatmak için kanatçıklarda soğutma kanalları açılarak nispeten düşük sıcaklıktaki hava akışı sağlanarak soğutma sağlanır. Ayrıca kanatçıklarda uygulanan termal bariyer kaplama (kısaca, TBC) sayesinde yüzey üzerine termal spreyleme ile zirkonyum oksit, alüminyum oksit gibi ısıl iletkenlik değeri oldukça düşük ince bir seramik tabaka uygulanarak parçanın yüksek sıcaklıktan korunması amaçlanır.[7]

Roket sistemleri gibi özellikle süpersonik hızlarda seyir eden hava araçlarında ablatif malzeme kullanımı ile, yüksek miktarda ısıya maruz kaldığında buharlaşarak ısıyı sistemden uzaklaştırır.

Yanma Odası gövde ve Nozul gibi statik elemanların ve konumlandırmasına göre hava aracı gövdesindeki etkileşimde olduğu diğer komponentlerin çalışmasını etkilemektedir. Özellikle Yanma odası ve nozulun hava aracı platformu içinde konumlandırıldığı koşullarda ısı kalkanı uygulaması, yalıtım açısından çözüm oluşturabilmektedir.

Ronald Edwin Quinn (1989) çalışmasında, gaz türbini motorunun motor akış yolundan geçen sıcak gazlar tarafından yaratılan aşırı sıcaklıklardan motor çerçevesini korumak için kullanılan bir ısı kalkanı sistemi ayrıntılı olarak tanımlanmaktadır. Sistem, özellikle uçak türbin motorları için tasarlanmıştır ve motorun arka çerçevesini korumak amacıyla kullanılır. Motor çerçevesi, motor rotorunu stator içinde doğru konumlandırmak için kullanılan yapısal montajlardan oluşur.[10] Başka bir çalışmada, altın kaplamaların jet motorları için ısı kalkanları olarak kullanılmasını anlatan bir çalışma yayınlamıştır. Altın kaplamaların düşük emisyon

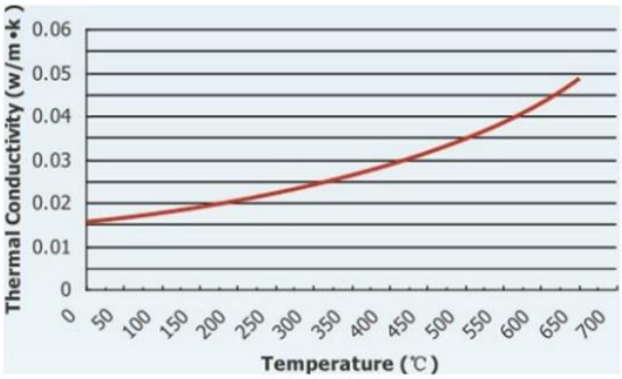
özelliklerinden yararlanarak, jet motorlarının aşırı ısıdan korunmasında ve ısı transferinin azaltılmasında etkili bir yöntem olduğunu göstermektedir.[6] Robert P. Czachor ve arkadaşları (1993), çalışmasında, gaz türbini motorunun dış kasası ile iç kısımları arasında ısı transferini en aza indirmek için tasarlanmış bir ısı kalkanı sistemidir. Bu sistem, özellikle yanma gazlarının akışı sırasında motor kasasını aşırı ısınmadan korumak için geliştirilmiştir. Isı kalkanı, kasaya bağlanır ve kasadan en azından kısmen içe doğru yerleştirilir.[8] Kalkanın dış yüzeyinde, kasanın iç yüzeyine doğru bakan ve hem eksenel hem de çevresel olarak uzanan bir oluk bulunur. Bu oluk, soğutma havasını kanalize etmek için tasarlanmıştır ve ısı kalkanının ısıya maruz kalan kısımlarına soğutma havasını hem çevresel hem de eksenel olarak dağıtır, böylece termal gradyanları azaltır.[9]John Raymond Hess ve arkadaşları (1993), çalışmasındaki ısı kalkanı mekanizması, özellikle motor çalışırken ısı transferini azaltmak ve motor yapısını sıcak gaz akışından korumak için bal peteği (honeycomb) hücrelerini kullanır. Petek hücreleri, gaz akışının boşluklardan geçişini engelleyen ve bu sayede ısı transferini azaltan yerel girdaplar oluşturmak için belirli boyutlarda tasarlanmıştır. Böylece, bu ısı kalkanı, gaz türbini motorlarının termal streslerini ve aşınma problemlerini en aza indirgemek için tasarlanmıştır.

2. TASARIM

2.1 Malzeme Seçimi

2.1.1 Yalıtım Malzemesi Seçimi

Isı kalkanında yalıtım malzeme seçimi yapılırken düşünülmesi gereken en önemli parametreler, yüksek sıcaklıkta çalışırken aynı zamanda düşük termal iletkenlik değerine sahip olması gerekmektedir. Literatür araştırmaları sırasında 2 çeşit yalıtım malzemesinin otomotiv havacılık ve endüstrisinde sıklıkla kullanıldığı göze çarpmaktadır. Bu malzemeler; Silika tabanlı Aerogel battaniye ve esnek seramik fiber (FCF) battaniyelerdir. Aerojel kullanımı; inşaat, tıp, ulaşım, metalurji ve havacılık gibi çok çeşitli alanlarda yaygın olarak karşımıza çıkmaktır. Bu kadar geniş kullanımının nedenleri arasında yüksek porozite, düşük yoğunluk, düşük termal iletkenlik ve dielektrik katsayısı örnek gösterilebilmektedir.[1] Esnek seramik fiberler yüksek sıcaklık direnci ve stabil kimyasal kompozisyonları ile ısı yalıtımı haricinde elektromanyetik dalga ve ses dalgaları absorbe edilmesinde kullanılmaktadır.[2] Aerogel battaniye, -50 ve +650 °C sıcaklık aralığında kullanılabilmekte olup bu sayede endüstriyel anlamda üretimi ve tercih edilirliği fazladır. Ayrıca hidrofobik yüzey özelliğine sahip olup su buharı geçiriciliği mevcuttur. 3, 6 ve 10 mm kalınlıklarda rulo formunda üretilmektedir. Figür 1'de 0-700°C sıcaklık aralığında sıcaklığa bağlı termal iletkenlik katsayısının değişimi grafiği paylaşılmıştır. Grafikten anlaşılacağı üzere 0.015 W/m.K'dan 0.05 W/m.K'ya doğru sıcaklıkla orantılı olarak termal iletkenlik de artmaktadır.

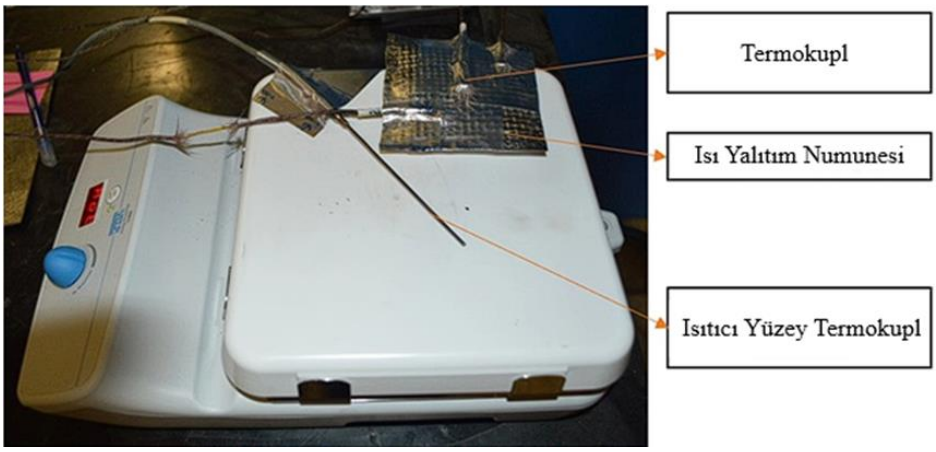


Şekil 1. Aerogelin sıcaklığa bağlı termal iletkenlik katsayısı değişimi [3]

Şekil 2. Aerogel Battaniye [4]

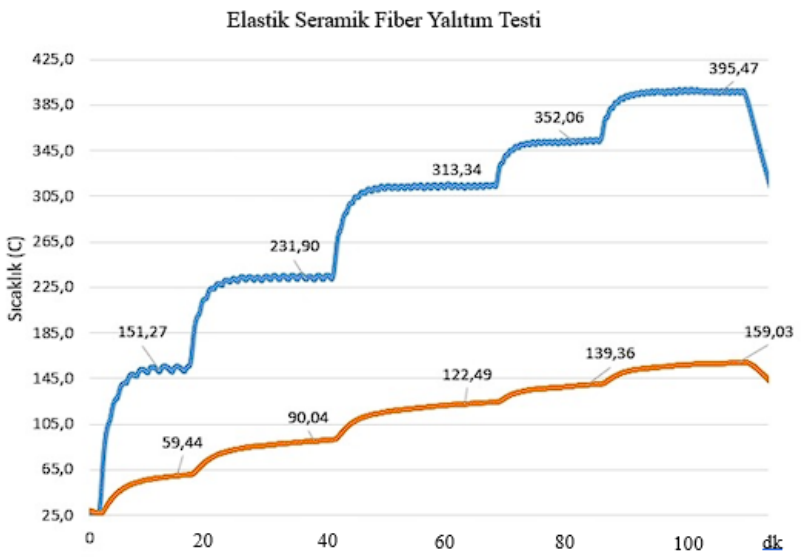
2.1.1.1 Yalıtım Malzeme Seçim Testi

Düşük iletkenlik değerine sahip bu iki ürünün termal iletkenlik değerlerinin kıyaslanması için test düzeneği hazırlanmıştır. Bu test düzeneğinde ısı tablası üzerine yerleştirilmiş iki ürünün 3 mm kalınlıklı numunelerine, bant ile sabitlenmiş termokupllar ile beraber yüzey sıcaklık ölçümü alınmıştır. Test kalemleri Şekil 3'te gösterildiği gibidir.

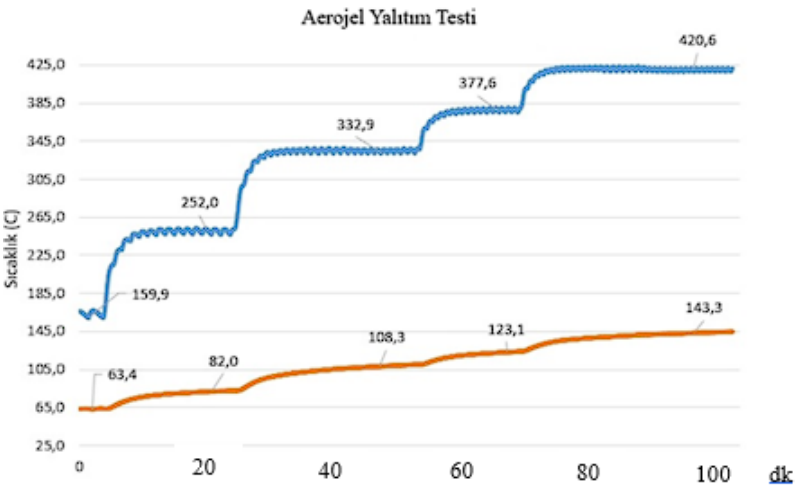


Şekil 3. Test Düzeneği

Isıtıcı tablanın ayarlanacağı test profili zamana bağlı olarak 20'şer dakikalık zaman adımları ile sıcaklığı kademeli olarak arttırılarak farklı sıcaklıklardaki yalıtım ürünlerinin davranışları incelenmiştir. İlk gerçekleştirilen test tekil olarak icra edilmiştir. Şekil 4-5-6'da malzemelerin tekil testleri ve sıcaklık karşılaştırmaları gösterilmektedir. Sıcaklık arttıkça iki ürün arasındaki yalıtım farkı daha da belirginleşmektedir. Örneğin ısıtıcı yüzeyde ölçülen 250°C'de iki yalıtım ürünü arasında yaklaşık 9°C fark olmasına karşın 350°C'de sıcaklık farkları 20°C'yi aşmaktadır. Bu sebeple iki yalıtım arasından, ısı kalkanında kullanılacak malzeme olarak Aerogel'in seçilmesi daha isabetli olacaktır.



Şekil 4. Esnek Seramik Fiber Yalıtım Testi



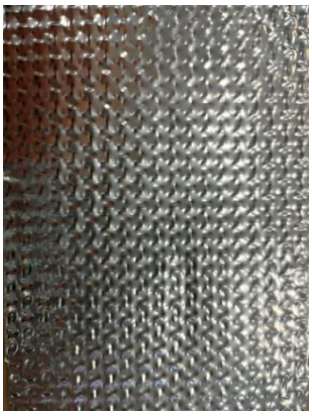
Şekil 5. Aerogel Yalıtım Testi

Şekil 6. Yalıtım Performansı Kıyas Testi

2.1.1 Yalıtımı Kapsayan Malzeme Seçimi

Aerogel battaniyeler yapısı gereği gözenekli polimer lifli yapıya sahiptir. Muhafazasız bir biçimde kullanıldığında partikülleri ortama dağılabilmektedir bu nedenle Aerogel'i saracak sıcaklık dayanımı yüksek ve hafif malzemeler tercih edilmektedir. Uygulama örnekleri incelendiğinde otomotiv, havacılık uzay sanayii gibi sektörlerde ince sac metal malzemelerin tercih edildiği görülmektedir bu sayede hem sıcaklık dayanımı yüksek hem de hafif ve kolay şekil verilebilmektedir. Endüstride ısı yalıtım ceketleri de tercih edilen seçeneklerden biridir. Özellikle, Endüstriyel fırınlar, vanalar, kazanlar ve ısı değiştiricilerde kullanılırlar. Dış katman olarak cam elyaf veya seramik elyaf kumaş gibi termal iletkenliği düşük malzemelerden imal edilmektedirler.

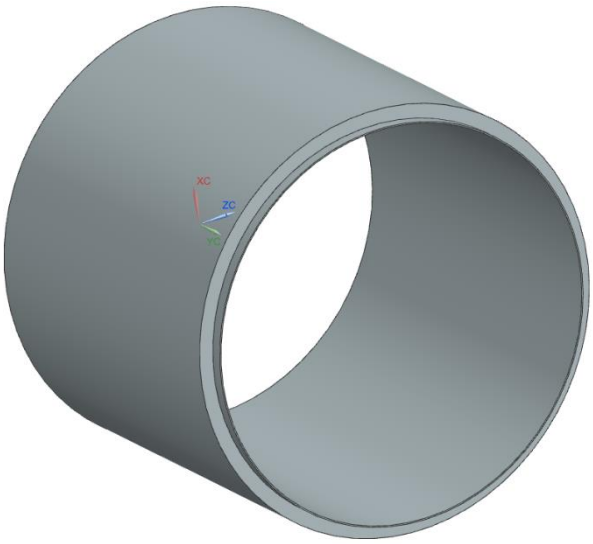
Yalıtım malzemesini muhafaza edecek dış katmanda seçim yapılırken cam elyaf kumaş ve sac metal malzeme kıyaslaması yapılarak seçim sağlanmıştır. Cam elyaf kumaşın sac malzemeye göre avantajları esnekliği sebebiyle karmaşık geometrilerde uygulanmasının daha kolay olması, sac metale oranla hafif olmasıdır, buna karşın sac metalin cam elyafa göre avantajlı olan özellikleri, sıcaklık, mekanik dayanımının daha iyi olması metallerin ısıyı yansıtıcı özelliğe sahip olması örnek gösterilebilir. Bu tez kapsamında sac metal ısı kalkanı seçilerek devam edilmiştir. Sebebi turbo jet motorların yaydığı yüksek sıcaklığa (1000 K ve üzeri sıcaklık) sac metalin dayanımının daha yüksek olmasıdır. Sac metal ısı kalkanının yanı sıra sacın düz veya gofrajlı olup olmaması da tasarım kriterleri arasında bulunabilmektedir. Gofraj kısaca, sacın mukavemetini ve yüzey alanını arttıran şekillendirme işlemidir. Şekil 7'de yankından çekilmiş gofrajlı sac görseli bulunmaktadır.



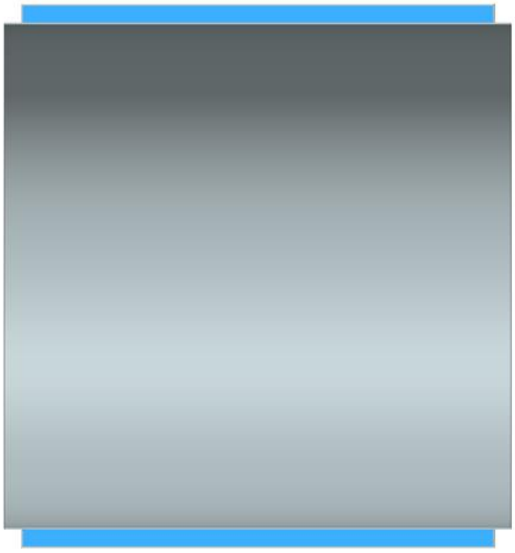
Şekil 7. Gofrajlı Sac

2.2 Geometri

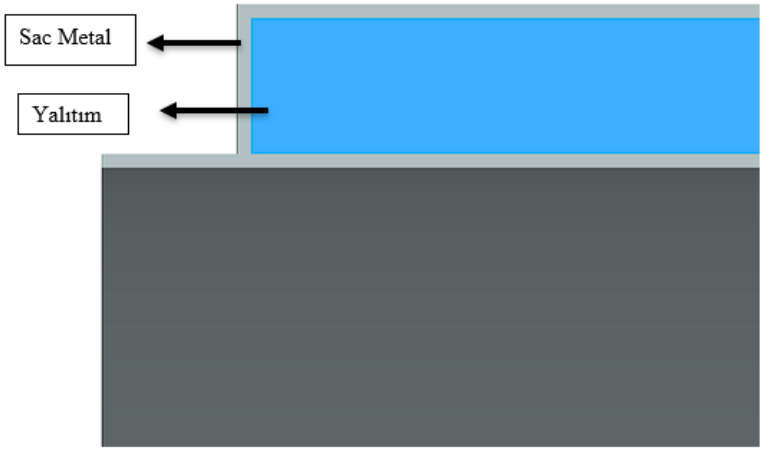
Silindir yapıdaki gövde için CAD ortamında modellenen ısı kalkanı görüntüsü Şekil 8'de, kesit görüntüsü ise Şekil 9 ve Şekil 10'da görüldüğü gibidir.



Şekil 8. Isı Kalkanı Geometrisi



Şekil 9. Isı Kalkanı Kesit Görüntüsü



Şekil 10. Isı Kalkanı Yakınlaştırılmış Kesit Görüntüsü

3.ARAŞTIRMA VE BULGULAR

3.1 Teori

Isı kalkanında kullanılacak ısı transfer mekanizması denklemleri aşağıda belirtildiği gibidir.

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+\dot{q}=\rho C_p\frac{\partial T}{\partial t} \quad (1)$$

2 boyutta ısı transferi, üretim ve zamana karşı ısı değişimi ihmali, sabit iletkenlik kat sayısına sahip olduğu kabul edilmiştir. Bu kabullerin başlıca sebepleri;

Isı kalkanının çapı, kalınlığının yaklaşık 50 katı olması sebebiyle silindir koordinat sitemi yerine kartezyen koordinat sistemi baz alınmıştır. Isı üretimi yanma odası içinde gerçekleştiği için, yanma odası tarafından çıkan ısı sıcaklığa sebep olacaktır. Yanma odası ve ısı kalkanı içinde üretim denkleme dahil edilmeyecektir. Tasarımı ve analizi yapılacak olan geometri silindir yapıya sahip olduğu için simetri mevcuttur. Bu sebepten ötürü tasarımı ve analizi iki boyuta indirgeyebilir, çıkan sonuçları 360° olarak varsayabilmektedir.

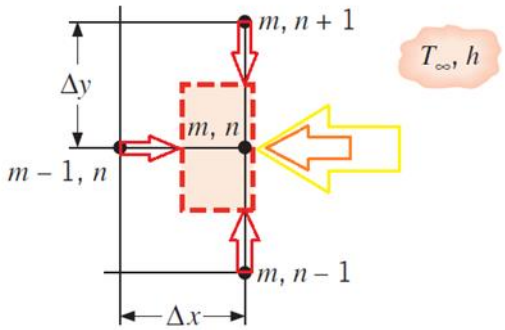
Yanma odası kendi içerisinde değişkenler göstereceği için radyal ve eksenel yönde gerçekleşecek ısı transferi farklılıklar gösterecektir. Ancak, doğru bir ısı kalkanı için sistemi daimî durumda (ing. steady-state) ve maksimum sıcaklık zamanında ele alınacaktır.

$$\frac{\partial}{\partial x}\left(\frac{\partial T}{\partial x}\right)\Big|_{m,n}=\frac{\left(\frac{\partial T}{\partial x}\right)\Big|_{m+1/2,n}-\left(\frac{\partial T}{\partial x}\right)\Big|_{m-1/2,n}}{\Delta x}=\frac{T_{m+1,n}-T_{m,n}-T_{m,n}+T_{m-1,n}}{\Delta x^2} \quad (2)$$

$$\frac{\partial}{\partial x}\left(\frac{\partial T}{\partial x}\right)\Big|_{m,n}=\frac{\left(\frac{\partial T}{\partial x}\right)\Big|_{m+1/2,n}-\left(\frac{\partial T}{\partial x}\right)\Big|_{m-1/2,n}}{\Delta x}=\frac{T_{m+1,n}-T_{m,n}-T_{m,n}+T_{m-1,n}}{\Delta x^2} \quad (3)$$

Denklem 2, x-yönünde olan ısı transferini, denklem 3, y-yönünde ısı transferini belirtmektedir. Ağ yapısında kullanılan simetri ile aynı doğrultuda iyi sonuçlar gösterdiğinden ötürü eşit bölgelere ayrılmıştır. Bu nedenle, Δx=Δy olarak kabul edilecektir. Bu kabul ile beraber denklem 1, denklem.2 ve denklem 3 aşağıdaki son halini alır.

$$T_{m,n+1}+T_{m,n-1}+T_{m+1,n}+T_{m-1,n}-4\,T_{m,n}=0 \quad (4)$$



Şekil 11. İletim, taşınım ve radyasyon transferlerini barındıran düğüm analizi [5]

Şekil 11, içerisinde kırmızı oklar ile gösterilen iletimden kaynaklanan ısı transferi, kahverengi ile gösterilen taşınımdan kaynaklanan ısı transferi, sarı ile gösterilen radyasyondan kaynaklanan ısı transferidir. Oklarla belirtilen ısı transferleri denklem 1.7, 1.8 ve 1.9 kullanılarak genişletilecektir.

Isı iletim, taşınım ve radyasyonu beraberinde barından ayrıklaştırılmış enerji denklemleri

$$q_{(m-1,n)\to(m,n)} = k(\Delta y \cdot 1)\frac{T_{m-1,n} - T_{m,n}}{\Delta x} \quad (5)$$

$$q_{(m,n+1)\to(m,n)} = k\left(\frac{\Delta x}{2} \cdot 1\right)\frac{T_{m,n+1} - T_{m,n}}{\Delta y} \quad (6)$$

$$q_{(m,n-1)\to(m,n)} = k\left(\frac{\Delta x}{2} \cdot 1\right)\frac{T_{m,n-1} - T_{m,n}}{\Delta y} \quad (7)$$

$$q_{(\infty)\to(m,n)} = h(\Delta y \cdot 1)(T_\infty - T_{m,n}) \quad (8)$$

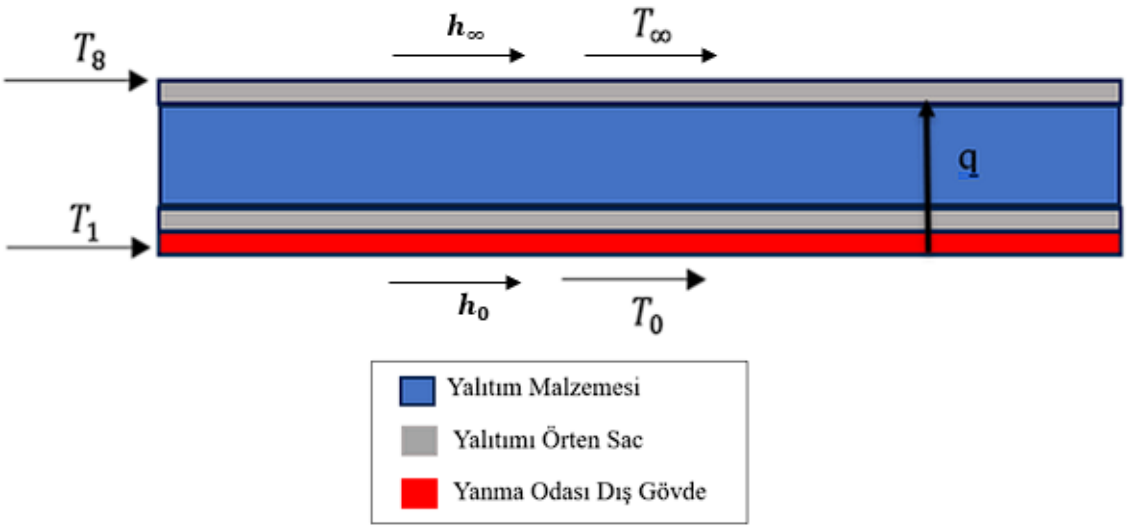
$$q_{(surr)\to(m,n)} = \in \sigma(\Delta y \cdot 1)({T_{surr}}^4 - {T_{m,n}}^4) \quad (9)$$

$$q_{(m-1,n)\to(m,n)} + q_{(m,n+1)\to(m,n)} + q_{(m,n-1)\to(m,n)} + q_{(\infty)\to(m,n)} + q_{(surr)\to(m,n)} = 0 \quad (10)$$

$$2\,T_{m-1,n} + T_{m,n+1} + T_{m,n-1} + \frac{2h\Delta y}{k}T_\infty + \frac{2 \in \sigma\Delta y}{k}{T_{surr}}^4 - \left(4 + \frac{2h\Delta y}{k}\right)T_{m,n} - \frac{2 \in \sigma\Delta y}{k}{T_{m,n}}^4 = 0 \quad (11)$$

Denklem 11'de olduğu gibi tüm düğüm noktaları için denklemler çıkartılır ve daha sonra tüm sistem matris haline getirilir. Getirilen matris bir hesaplama aracı ile çözülmeye başlanır. Termal haritalama bu sayede sağlanmış olur.

Isı kalkanı kesiti temsili olarak kesit görüntüsü Şekil 12'de gösterildiği gibidir. Gri renkli görüntü yalıtımı örten sacı, mavi renkli kısım yalıtım malzemesi, kırmızı renkli kısımda yanma odası gövdenin dışını göstermektedir. İçerisinden geçen akışkanın taşınım kat sayısı h_0 olarak, dış ortamdaki taşınım katsayısı h_∞ belirtilmektedir.

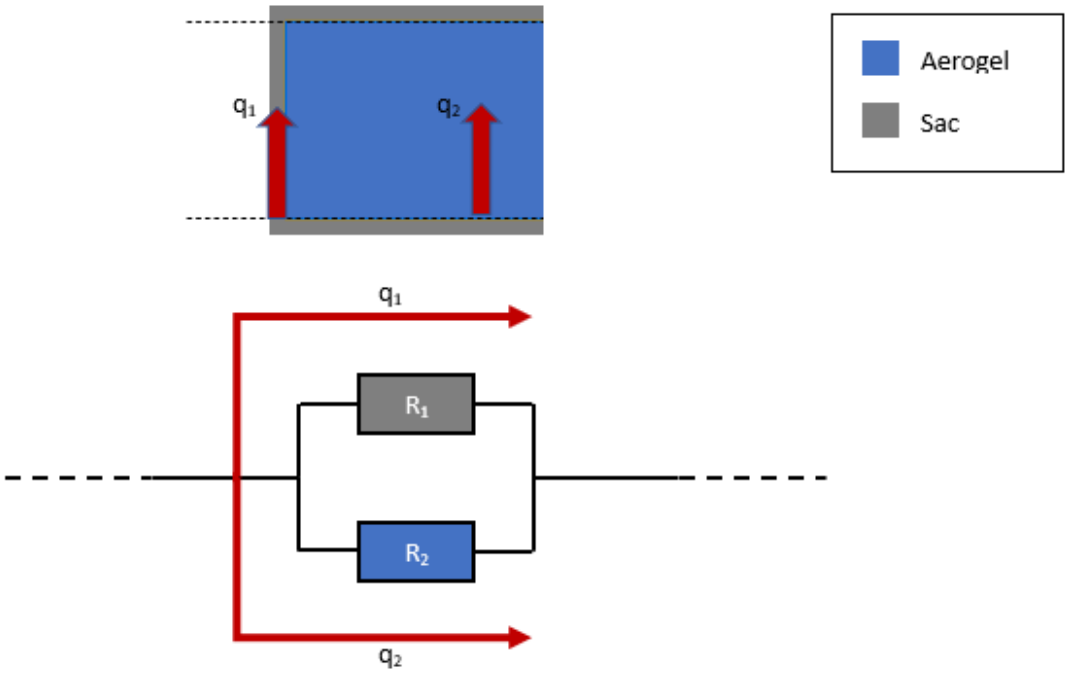


Şekil 12. Isı kalkanı referans kesit görüntüsü

3.1.2 Termal Köprü Oluşumu

Termal köprü, katmanlı oluşturulması düşünülen bir tasarımda, birleşme noktaları üzerinden, birleşme noktalarının materyalinin yalıtım malzemesinden çok daha yüksek iletkenlik kat sayısına sahip olmasından dolayı ısının kendisini bu köprü üzerinden iletmesidir.[11] Bunun başlıca sebebi ısı, elektrik akımlarında da görüldüğü gibi, paralel devrelerde, direncin daha düşük olduğu bağlantıdan geçme eğilimindedir. Aşağıda bir

termal köprü oluşması sonucu olası ısı transferinin hesabı gösterilmektedir. Şekil 13'te termal köprünün oluşması hakkında bir benzetme yer almaktadır.



Şekil 13. Termal Köprü Gösterim

$$R_1'' = \frac{\Delta y}{k_{sac}} = \frac{1}{16.2\ W/mK} \approx 0.062\ mK/W \tag{12}$$

$$R_2'' = \frac{\Delta y}{k_{Aerogel}} = \frac{1}{0.02\ W/mK} \approx 50\ mK/W \tag{13}$$

Sac ve Aerogel dirençlerine bakıldığında Aerogel direnci sac direncinden yaklaşık olarak 806 kat fazladır. Isı, düşük dirençten geçme eğilimi gösterir. Sac direnci yalıtıma göre çok düşük olduğundan, devre kendini sac üzerinden tamamlayacaktır. Bu sebepten ötürü, termal köprü olan bölgelerde sıcaklık çok yüksek çıkacaktır. İlgili durum özellikle yalıtımın bitip sacın birleştiği dış yüzeylerde açığa çıkmaktadır.

3.1.3 Isı Kalkanındaki Gofraj Etkisi

Tasarım kısmında belirtildiği gibi sac yapıya gofraj şekillendirme sırasında yırtılma meydana gelmemesi için mukavemeti arttırmaktır. Gofrajlanmış yüzey mukavemet için avantaj yaratırken, aynı anda yüzey alanı büyüdüğü için ısı transferini de arttırmaktadır. Gofrajlar başka bir açıdan ısı kalkanı üzerinde fin görevi görmektedir.

Gofrajlanmış alan, ortalama 1 mm uzunluğunda ve yüksekliğinde, 5 mm genişliğinde finler çıkartmaktadır. Gofrajın etkisini daha iyi anlamak için verim hesabı yapılması için, gofrajın en uç tarafının taşınım ile ısı transferine devam edeceği varsayılmaktadır. Teorik olarak verim hesabı için fin etkinliği denklem 15'te paylaşılan fin ısı transfer oranı, q_f, değerinden hesaplanır. Denklem 15-16-daki kat sayılar, sabit kesit alanındaki finlerde kullanılan genel enerji denklemindeki lineer, homojen ikinci dereceden kısmi diferansiyel denklem çözümünde kullanılan kat sayılardır.

$$q_f = M\frac{\sinh mL + (h/mk)cosh\ mL}{\cosh mL + (h/mk)sinh\ mL} \tag{14}$$

$$m^2 = \frac{hP}{kA_c} \tag{15}$$

$$M = \sqrt{hPkA_c}\theta_b \tag{16}$$

$$\varepsilon_f = \frac{q_f}{hA_{c,b}\theta_b} \tag{17}$$

$$M = \sqrt{\left(55\frac{W}{m^2K}\right)[2\cdot(5\ +1)mm\cdot 10^{-3}\,{}^{m}/_{mm}](17\ W/mK)\left[(5\ mm\cdot 1mm)\cdot 10^{-6}\ {}^{m^2}/_{mm^2}\right]40K} \tag{18}$$

$$M = 0.3\ W \tag{19}$$

$$q_f = 0.3\ W\frac{\sinh\ (88.117\frac{1}{m}\cdot 0.001m) + \left(\frac{55\frac{W}{m^2K}}{(88.117\ m^{-1}\cdot 17\ W/mK)}\right)cosh\ (88.117\frac{1}{m}\cdot 0.001m)}{\cosh\ (88.117\frac{1}{m}\cdot 0.001m) + \left(\frac{55\frac{W}{m^2K}}{(88.117\ m^{-1}\cdot 17\ W/mK)}\right)sinh\ (88.117\frac{1}{m}\cdot 0.001m)} \tag{20}$$

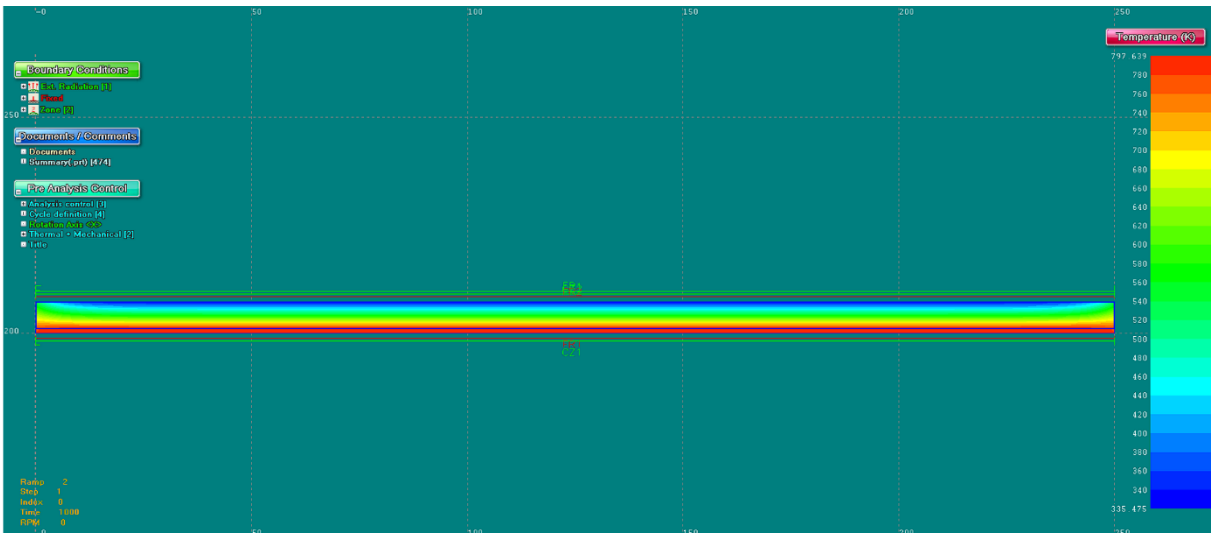
$$\varepsilon_f = \frac{0.03}{\left(55\frac{W}{m^2K}\right)\left[(5\ mm\cdot 1mm)\cdot 10^{-6}\ {}^{m^2}/_{mm^2}\right](40\ K)} \cong 2.72 \tag{21}$$

Denklem 18'in hesaplanması sonucunda elde edilen değer, gofrajın etki mertebesini göstermektedir. Gofrajın fin etkinlik değerinin 2'den büyük olması finlerin ısı transferinde önemli etkisinin olduğunu belirtir. [5]

3.2 2 Boyutlu Analiz

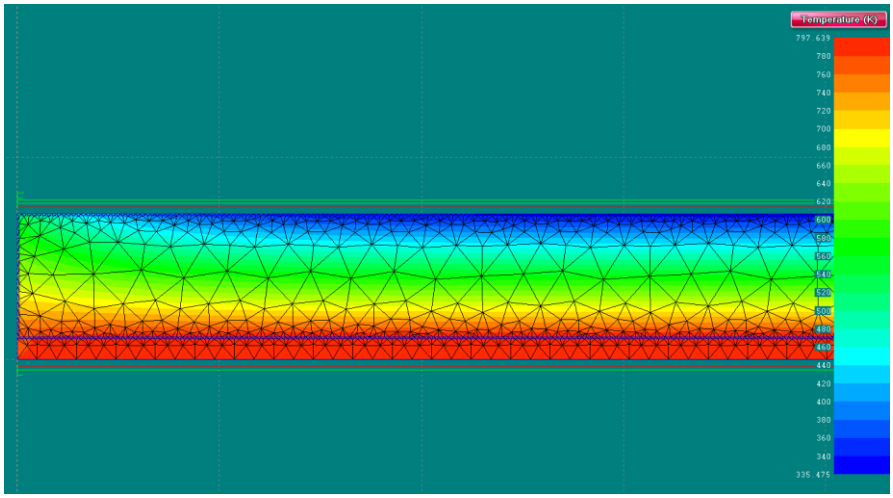
Tasarım çalışması, SC03 ortamında analize tabi tutulmuştur. Aşağıda yer alan iki termal analizde 6 mm ve 10 mm yalıtım malzemesi kullanılmıştır.

Analiz varsayımında örnek olarak 0,3 metre çaptaki yanma odası içinden zorlanmış taşınım ile 247 m/s, yaklaşık 0.7 Mach hızda, 800 K sıcaklıkta daimî akış koşullarında hava akışı ve yalıtımın dışında kalan ortamdaki referans sıcaklığı 288 K olarak tanımlanıştır. İçerisinden geçen akışkanın taşınım kat sayısı h_0 =55W/m²K olarak alınmıştır. Yalıtımın termal iletkenlik değeri sabit 0,04W/mK olarak kullanılmıştır. Yanma odası gövde ile ısı kalkanı arasında kontak direnç tanımlanmıştır. Isı kalkanı dış yüzeyinde doğal taşınım ve radyasyon tanımlaması yapılmıştır. Çözüm ağında Tri-6 elemanlı, 10^6 adet düğüm noktası oluşturulmuştur. Çözüm ağından bağımsızlık elde edilmiştir.



Şekil 14. 6 mm yalıtım malzemesi kullanılan Isı kalkanı bütünü termal analiz sonucu

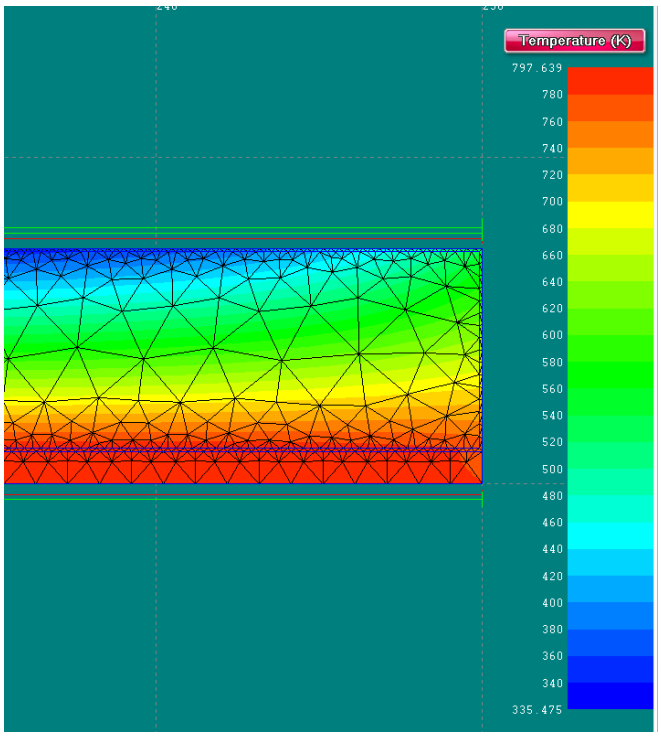
Şekil 14'te yer alan görselde, tasarımı tamamlanan ve 6 mm kalınlıkta yalıtım malzemesi kullanılmış ısı kalkanında sıcaklık dağılımı görülmektedir. 798 K sıcaklığa ulaşan gövdenin, ısı kalkanı sonucu yüzey sıcaklığı 335 K görülmüştür. Merkez bölgesinde %58 sıcaklık düşüşüne ulaşılmıştır.



Şekil 15. Isı kalkanı sol köşe birleşim noktası

Şekil 15'da görüldüğü üzere Isı kalkanın sol köşesinde sac birleşmesi olduğu için termal köprü oluşmuş bulunmaktadır. Termal köprü, sacın iletim katsayısı çok daha yüksek olduğu için, ısının yalıtım malzemesi yerine sac tarafından akmasına sebebiyet vermektedir. Bu nedenden ötürü, ısı kalkanı sol taraf birleşme noktasında 600 K-650 K varan sıcaklık görülmektedir.

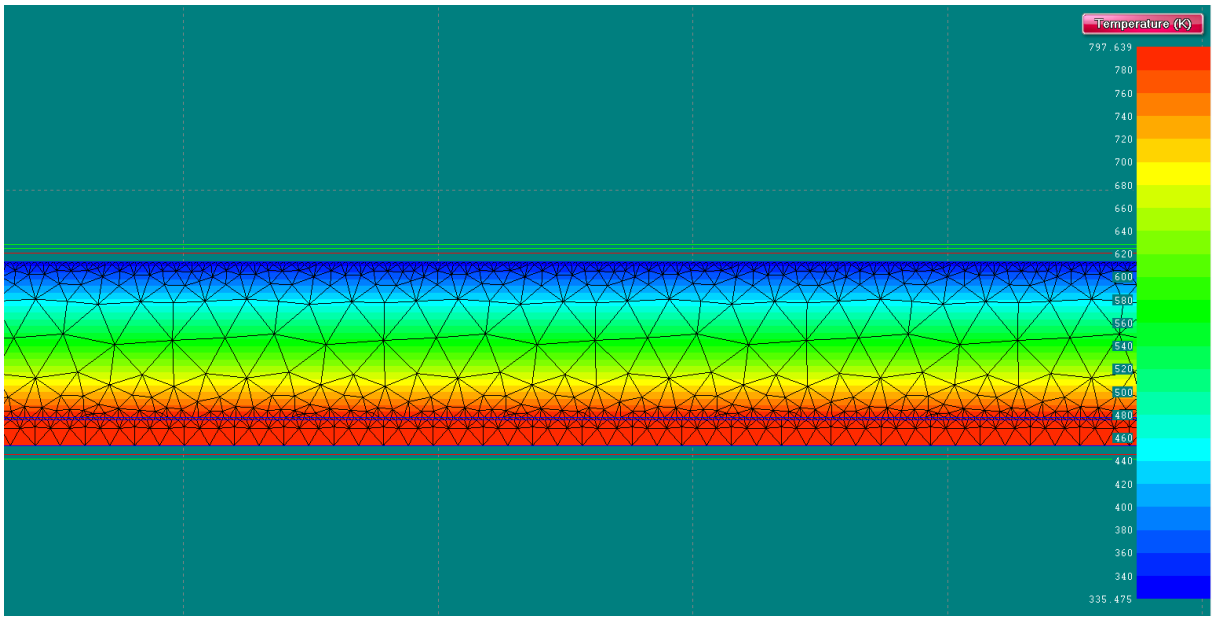
Şekil 16'daki sonuçlara göre ısı kalkanı sağ birleşme noktası, sol birleşme noktası gibi termal köprü sebebiyet nedeniyle 600 K-650 K sıcaklıklar görülmektedir.



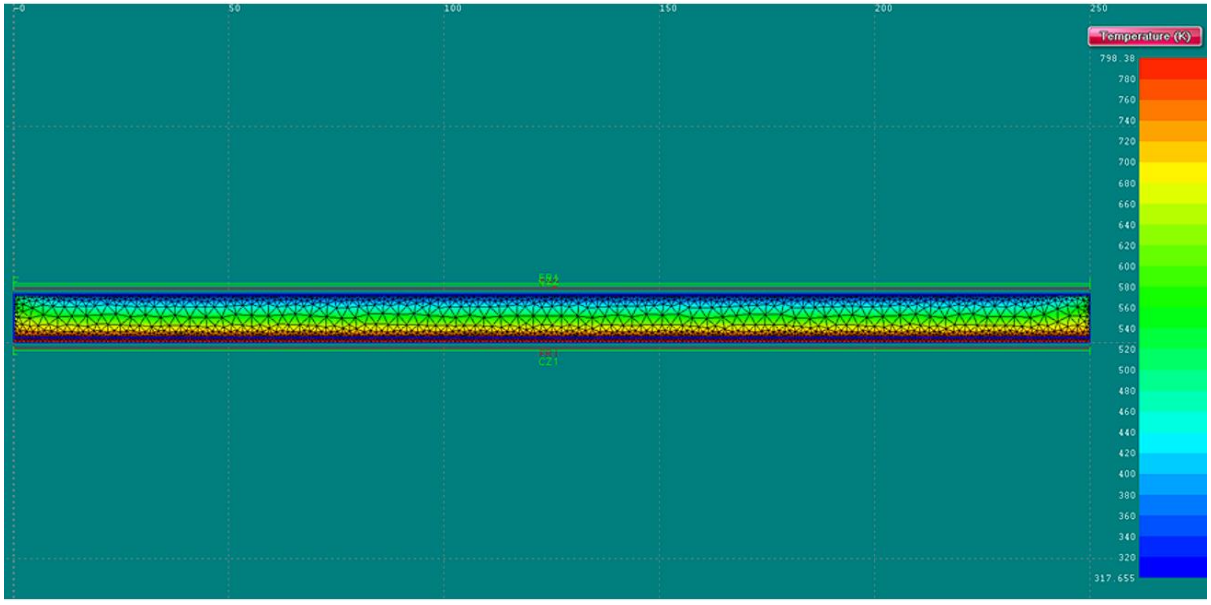
Şekil 16. Isı kalkanı sağ köşe birleşim noktası

Termal köprü sebebi ile iki köşede gözüken yüksek sıcaklıklar, bir ısı kalkanı tasarımı yapılırken tasarımda en az miktarda üst kısımda birleşme noktası yapılması gerektiğini göstermiştir.

Şekil 17'de görülen ısı kalkanı merkez bölgesinde katmanlar arasında sıcaklık dağılımı oldukça homojendir. Özellikle yüzey sıcaklığı bu bölgede minimum olarak görülmüştür. Birleşme noktalarından uzaklaşıldıkça sıcaklık çok büyük ölçülerde düşüşler göstermektedir.



Şekil 17. Isı Kalkanı Merkez Bölge



Şekil 18. 10 mm yalıtım malzemesi kullanılan ısı kalkanı bütünü termal analiz sonucu

Şekil 18'de görüldüğü üzere, 4 mm kalınlık artışı sonucu dış yüzey sıcaklığı 317 K değerine düşmüştür. Aynı şekilde çıkan ısının azalması sonucu gövde kısmında 798 K sıcaklığa çıkmıştır. Bu değerlere göre, 10 mm ısı kalkanında yüzey sıcaklığı % 60 azaltılmış olup, yalıtım malzemesinin hacim olarak % 68 arttırılması sonucunda dış yüzey sıcaklığında %5.3 değerinde bir düşüş daha gerçekleştiği görülmüştür. Tablo 1'de sonuçlar özetlenmiştir.

Tablo 1. Analiz Sonuçları

	10 mm yalıtım	6 mm yalıtım
Dış Yüzey Sıcaklığı	317 K	335 K
İç Gövde Sıcaklığı	798 K	798K

4. SONUÇLAR

Bu çalışma sonucunda turbojet motorların yanma odası gövdesinde uygulanan ısı kalkanlarının literatürdeki bazı örnekleri, yalıtım performansında hesaplanacak ısı transfer metotlarının incelenmesi, malzeme seçim kriterleri, tasarım adımlarının belirlenmesi gibi hususlar ortaya çıkarılmıştır. Malzeme teknolojisinin gelişmesiyle beraber daha düşük termal iletkenlik değerine sahip malzeme kullanımı ile daha iyi yalıtım sağlanabileceği aşikardır nitekim endüstride de yaygın olarak kullanılan Aerogel battaniyelerin 0,02W/mK-0,05W/mK gibi düşük iletim değeri ile beraber turbojet motorun yanma odası dış gövdesinde ciddi ölçüde sıcaklık düşüşü olabileceği saptanmıştır. Termal iletkenlik değerinin bu derece düşük olması Aerogel kullanımındaki kalınlık miktarındaki değişimin analiz başlığı altında belirtildiği üzere dramatik değişikliklere yol açtığı görülmüştür. Öte yandan yalıtımın bittiği uçlarda, diğer bir değişle sac birleşim yerlerinde, çalışmanın tasarım bölümünün alt başlığında belirtilen termal köprü oluşumu hipotezi, analiz sonuçları ile beraber doğrulanmıştır. Analizde kalınlığa bağlı sıcaklık değişiminin görülmesi için kalınlık dışındaki diğer parametreler akış ve sıcaklık koşulları sabit tutularak analiz gerçekleştirilmiştir. Malzemelerin doğası gereği maruz kalınan sıcaklığa bağlı olarak termal iletkenlik değerinde ve dolayısıyla yalıtım performansında değişim olabileceği unutulmamalıdır. Gofrajlı yapıdaki sac kullanımının performansa majör bir etki oluşturmamakla beraber düz sac ile kıyaslanması, genel itibari ile tasarım ve analizin validasyonu için test faaliyetlerinin yürütülmesi, ısı kalkanı üzerinden termal etiket, termokupl veya termal kamera uygulamaları ile enstrümantasyon yapılabilir.

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EXPERIMENTAL INVESTIGATION OF OIL-WATER SEPARATION EFFICIENCY

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ABSTRACT

The need for energy in the world is increasing day by day, and accordingly the search for new energy sources continues. Although the interest and investment in renewable energy has increased recently, the use of non-renewable (fossil-based) energy resources still maintains its top position. Among fossil energy sources, it is inevitable that the importance of petroleum, which is the most preferred and consumed, will increase. In this case, it is important to benefit as much as possible from the petroleum that is already extracted to the surface at high costs. Petroleum extracted to the earth; Since it consists of a mixture containing water, mud and some gas, it is first crash at high speed against the plates placed horizontally in the tank and kept in the relevant tank for a certain period of time. By this method, separation of most of the gas and sludge in the mixture is achieved. This process is called the first process, and as a result of this process, crude petroleum, separated water (wastewater), sludge, and gas are obtained. The obtained separated water may contain 20%-5% petroleum. Some processes are applied within the scope of the second process to separate this petroleum in the waste water. In this study, within the scope of the second process, corrugated plates were used based on the gravitational separation method, which is widely preferred because it does not require any energy source in the separation of petroleum in waste water and provides separation to a large extent. In order to consider the effect of corrugated plates on the separation efficiency, 3 (three) different hole diameters (15, 35, 55 mm) and 3 (three) different plate lengths (600, 800, 1000 mm) parameters were considered. Also the individual and compound effects of each parameter on the separation efficiency were examined. In all experiments, the same petroleum-water mixture samples (88% water, 12% petroleum) were used and the temperature of the relevant samples was kept at 23 °C. The change in the separation efficiency of the petroleum-water mixture pumped into the separation system at a constant flow rate of 20 liters/minute was examined according to the parameters. The petroleum/water ratio of the mixture pumped into the system and the petroleum/water ratio of the water separated from the system were measured, and the difference between the two measurements was considered as the separation efficiency. As a result of the measurements, it was seen that each parameter considered affected the separation efficiency both individually and relatively. It was observed that the highest separation efficiency of 98.75% was obtained when the plate hole diameter was 55 mm and the plate length was 800 mm.

Keywords: Oil-water separation, gravitational separation, separation efficiency, corrugated plates.

INTRODUCTION

The need for energy is increasing day by day due to the development of science, the use of technology in all areas of life and this situation getting more advanced day by day.

As the need for energy increases, the number of studies on new energy sources increases. Although renewable energy sources have become popular in recent years, fossil-based energy sources (non-renewable) still rank first in use (Malakhov et al., 2023). When fossil energy sources are examined, it is seen that petroleum is the most used fossil energy source. It is inevitable to make maximum use of the petroleum that is delivered to the surface from underground with great costs and difficulties (Zhang et al., 2020). Oil extracted from underground contains water, solid particles and some gas. The relevant petroleum-gas-water-solid particle mixture is first hit at high speeds on plates positioned horizontally in a tank (Ihsanullah and Bilal, 2022). Within the scope of this process, called the First Process, the majority of the gas and solid particles in the mixture are separated.

Some of the water in the mixture (80-95%) is separated. The separated water contains 20-5% petroleum. The relevant water is called separated water and is treated as waste and injected back into the ground. Separation of the relevant mixture containing 20-5% petroleum is carried out within the scope of the Second Process (Mirzaei, 2021). There are many methods used within the scope of the second process. The most preferred method is the gravitational separation method as it does not require any energy source or chemical management (Wang et al., 2019). For this reason, corrugated plates were used within the scope of the gravitational separation method in the relevant study.

A separation procedure is used to keep two or more fluids in a combination or contaminants from any product separate. Separation devices are widely employed in many industries, including marine, textile, food, transportation, metal, and petrochemical. For example, air-water separators are critical components of the intake system of marine diesel engines because moisture in the air generates water droplets on the cylinder walls (Jie et al., 2020). Because crude petroleum cannot be used directly without further processing, its water, petroleum, and gas constituents should be decomposed in petroleum (Yayla et al., 2017).

In the food industry separation is generally used to remove specific components from the product and purify the fractions (Brennan et al., 2006). There are tremendous kinds of separators in engineering to fulfill such purposes. Membrane (Liu et al., 2017), gravity (Nayak et al., 2021), inertia (Brian et al., 2023), filtration (Rowe et al., 2013), coalescence (Oruc and Yayla, 2022), and the centrifugal (Peng et al., 2005) types are among them. The corrugated plate separation is the organic combination of gravity and coalescence separation. This type of separation is superior to others owing to its feasibility, low operating cost, high processing capacity, low resistance but high efficiency, and small pressure drop loss (Han et al., 2017). The corrugated plate separators which also are the subject of this study are based on the difference of gravitational forces on the light and heavy fluids forced to flow between the corrugated plates. These plates provide passages for crossing gas flow and sufficient direction change for heavy fluid to coalesce and drain on the wavy plate surface. Corrugated plate separators are generally designed as a series of parallel, narrow curved passages, each of which includes several periodic curved waves. Several parameters may affect the separation performance of the separator such as the distance between the plates, the bending angle of the plates, the length and the number of each stage, the hole diameter, size, and position of the holes if the plates are equipped with them (Mao et al., 2020).

In order to consider the effect of corrugated plates on the separation efficiency, 3 (three) different hole diameters (15, 35, 55 mm) and 3 (three) different plate lengths (600, 800, 1000 mm) parameters were considered. Also the individual and compound effects of each parameter on the separation efficiency were examined. In all experiments, the same petroleum-water mixture samples (88% water, 12% petroleum) were used and the temperature of the relevant samples was kept at 23 °C. The change in the separation efficiency of the petroleum-water mixture pumped into the separation system at a constant flow rate of 20 liters/minute was examined according to the parameters. The petroleum/water ratio of the mixture pumped into the system and the petroleum/water ratio of the water separated from the system were measured, and the difference between the two measurements was considered as the separation efficiency. As a result of the measurements, it was seen that each parameter considered affected the separation efficiency both individually and relatively.

MATERIALS AND METHODS

In the second process, the petroleum-water mixture was separated using corrugated plates. The relationship between hole diameter and length of corrugated sheets and the effect of related parameters on separation efficiency were examined experimentally.

In addition, as seen in Figure 1, the rheological properties (density, viscosity) of all fluids entering and exiting the system separately were measured in the relevant calculations.

Figure 1. Viscometer and density meter used

The viscosity, density and petroleum ratio of the first Processed petroleum-water mixture sample from Batman Batı Raman petroleum production was measured and indicated in Table 1.

Table 1. Properties of petroleum-water mixture

Ratio of Petroleum in Water (%)	Density (kg/m3)	Viscosity (Pa.s)
12	770	6 x 10-3

The properties of the corrugated plates used in the separation system are given in Table 2, and the separation was achieved through the sets established using the corrugated plates with the specified properties, and all relevant experiments were carried out.

Table 2. Properties of the corrugated plates used in the experiments

Corrugated Plate Length (mm)	600, 800, 1000
Corrugated Plate Width (mm)	400 mm
Distance Between Corrugated Plates (mm)	14 mm
Corrugated Plate Hole Diameter (mm)	15, 35, 55

The petroleum-water mixture pumped into the separation system; Separation is provided by passing through sets consisting corrugated plates seen in figure. Petroleum droplets in the mixture passed through corrugated plates (Figure 2) stick to each other and collect on the surface like a film strip. Since the density of crude petroleum is lower than the density of water, the separated water is collected at the bottom of the separation tank.

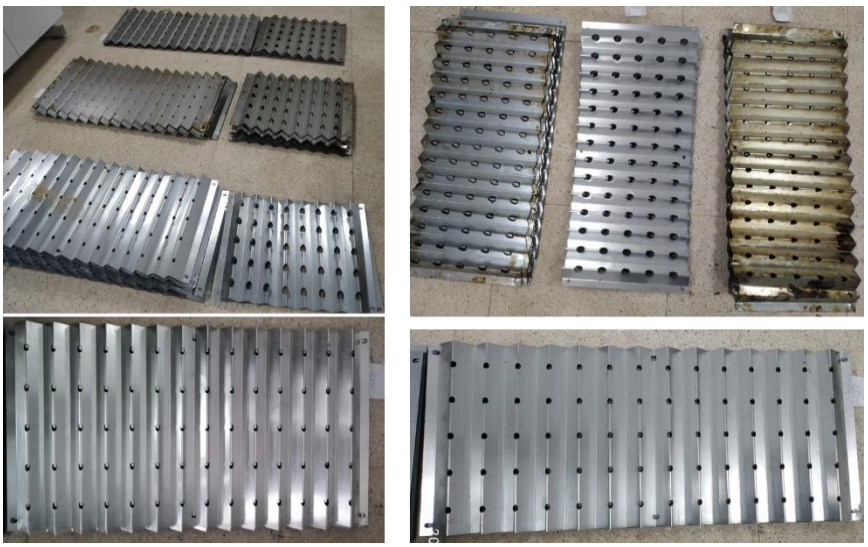

Figure 2. The corrugated plates

The water ratio of the petroleum-water mixture before pumping to the purification system and after purification was determined with the Karl Fischer Volumetric device. The detailed report created in the Karl Fischer Combimethanol as solvent and Combititrant-S as titrant were injected into the Karl Fischer titration vessel with the help of a pumped magnetic stirrer. During the analyses, the titrant mixture was mixed with a magnetic stirrer for approximately 30 minutes to obtain a more homogeneous mixture before the petroleum-water mixture sample was dropped into the system.

Figure 3. The separating system

As seen in Figure 3, the petroleum-water mixture is first kept in the feed tank. The mixture is stirred for 30 minutes to ensure a homogeneous mixture in the relevant tank. After the pumping flow rate and temperature of the mixture to the separation system are determined, the relevant mixture is pumped to the separation system. When contact begins with the corrugated plates in the separation tank, the separation process begins and the separated petroleum accumulates on the surface. Separated water is discharged from the bottom of the tank.

FINDINGS AND DISCUSSION

Experiments were carried out for 2 different parameters and 3 values of each parameter considered within the scope of the relevant study. The separation efficiency values obtained as a result of the experiments performed depending on the parameters taken into account, as well as the test list, are shown in the table below.

Table 3. The experiments carried out

Experiment No	Hole Diameter of Plates (mm)	Length of Plates (mm)	Separation Efficiency (%)
1	15	600	94,75
2	15	800	97.25
3	15	1000	95.45
4	35	600	95.75
5	35	800	98.25
6	35	1000	96.45
7	55	600	96.25
8	55	800	98,75
9	55	1000	95.45

In determining the optimum hole diameter value in the separation process, it is important that the petroleum droplets adhering to each other can easily come to the surface through the relevant holes. During the separation process, through the holes in the plates, there is a stagnation points in the flow and separation points are formed, and the petroleum droplets that stick together move more easily upwards from the holes and accumulate on the surface. Since the petroleum content in the mixture is high, the diameter of the petroleum droplets that stick together during separation is high. Therefore, maximum separation efficiency was achieved at the highest value of the hole diameter (55 mm). For this reason, it can be said that the hole diameter affects the separation efficiency.

The separation process begins as soon as the petroleum-water mixture entering the separation system comes into contact with the plates and begins to flow over the plate surface. The separation process may continue from the starting point to the ending point of the relevant plates. However, in the relevant study, it is seen that the separation process is ineffective after the length of 800 mm. Depending on the hole diameter and other fixed parameters, the optimum plate length value can be said to be around 800 mm.

CONCLUSION AND RECOMMENDATIONS

Within the scope of the relevant study, a series of experimental studies were carried out for 2 different parameters and 3 different values of each parameter for the separation of petroleum-water mixture. The results obtained as a result of the relevant study are listed below.

- Within the scope of the relevant study, 3 different values of each parameter were considered in order to examine the effect of plate length and plate hole diameter on separation efficiency.
- It was observed that both parameters considered affected the separation efficiency. It has also been noticed that the relevant parameters affect each other. It was concluded that the highest separation efficiency depends on the hole diameter and plate length values.
- The basic principle in the separation process is that the optimum design should be designed so that the undissolved petroleum droplets in the mixture can stick to each other and easily float to the surface.

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AN ANALYSIS ON TURKEY'S PREVIOUS RENEWABLE ENERGY SUPPORT MECHANISM

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ABSTRACT

This study is related to the Renewable Energy Resources Support Mechanism (YEKDEM) announced in 2021. YEKDEM aims to encourage investors to invest more in this field. Giving these incentives in this way is of course beneficial, but it is debatable whether they are sufficient. For this, an analysis covering the years July 2021 and July 2023 has been carried out for solar energy. In the analysis, the incentive amounts have been found as TL-kurus per kWh and the incentive amounts given to the investor have been calculated by converting them into cents US$/kWh. Incentive amounts are highest in July and lowest in January. In this 24-month period, a total incentive amount of 545.57 is found in TL-kurus/kWh and the equivalent of this value is 33.70 cents US$/kWh.

Key words: Solar energy, Solar power plant, YEKDEM

Introduction

The energy demand and installed capacity of countries are increasing proportionately day by day due to a variety of factors such as population expansion, technical development and industrialization, and an increase in people's living standards. The energy crisis is no longer a domestic issue for individual countries; same time, It has also increasingly become a worldwide problem. While energy used to be a tool for meeting people's basic needs, it has now evolved into a force that drives worldwide politics. Nowadays, fossil-based nonrenewable energy resources account for more than 80% of global energy consumption, with oil, coal, and natural gas being the most common [1,2]. Oil has a 32 percent stake, coal has a 27 percent share, and natural gas has a 22 percent share. Oil and natural gas have been extensively employed in recent decades, owing to many factors such as increased energy demand and evolving technologies, following the largely biomass and coal era. The phenomena of climate change, often known as global warming, has come from this relatively rapid growth in fossil fuel consumption [1,3]. Human activities have contributed around 1.0 degree Celsius of global warming above pre-industrial levels, according to the Intergovernmental Panel on Climate Change (IPCC), and global warming is expected to reach 1.5 degrees Celsius between 2030 and 2052 if current trends continue [1,3].

Concerns about global warming have made it impossible to assess energy-related issues on their own. Scientists have been looking for new energy sources and conversion methods to replace fossil-based ones, particularly since the 1973 oil crisis, which was exacerbated by environmental difficulties in the following years. solar, wind, geothermal, bio, and wave energies, as well as energy vectors like hydrogen, have been the dominant alternative energy sources since they are clean and renewable. The industrialized countries have been able to invest in such energy conversion systems and enhance their technologies since these energy sources are sustainable and environmentally benign. In the medium and long term, renewable energy technologies continue to be important [1,4].

The world's total renewable energy capacity, excluding hydro, reach 1179 GW by the end of 2018 [4]. PV power accounted for 480 GW of the total capacity [5]. Solar PV power accounts for 40.7% of all renewable energy installed power worldwide as of 2018 [5]. On the Asian continent, 263 GW of the total 480 GW installed electricity is located [6]. With 175 GW of installed PV electricity, China leads the continent [6]. China is followed by Japan, which has 56 GW of installed power [6]. Asia is followed by Europe with an installed

power of 115 GW, excluding Turkey [5]. In addition, the EU's total installed PV capacity is nearly equal to the entire continent. With 45 GW of installed capacity, Germany is the EU's largest installed capacity [5]. With an installed capacity of around 74 GW [5], the American continent ranks third among the continents. With 62 GW [5], the United States has the most installed capacity on this continent.

According to the expected growth rate of PV capacity, the global cumulative PV capacity is predicted to reach 1 TW between 2025 and 2030 [7]. The growth rate of PV capacity has been governed to a considerable extent by the efficiency and manufacturing cost of various types of PVs, as well as many other factors such as country incentive programs and climate change. Based on the fact that the trend in PV module manufacturing costs corresponds to the learning curve theory, crystalline Si and CdTe might have manufacturing costs of less than 0.2 $/W by 2030 if the learning rate remains constant [7]. Vartiainen et al. [8], on the other hand, looked at numerous scenarios to estimate the increase rate of PV capacity by 2050. They conducted analyses with a 30% learning rate for the base case, as well as sensitivity analyses with 20% and 40% learning rates for a moderate price fall scenario and a fast price decrease scenario, respectively. According to their calculations, cumulative PV capacity in 2050 might be at 9, 20, and 62 TWp, for the slow, base, and fast growth scenarios. In terms of EU developments, the EU Commission established a political agreement in 2018 on the increased use of renewable energy in the EU, in which the renewable energy target for the EU was set at 32% for 2030 [9]. Another agreement, the "Green Deal," was agreed at the end of 2019 in the EU, with the goal of becoming climate-neutral by 2050 [10]. In comparison to 1990 levels, the Green Deal calls for an accelerated reduction of greenhouse gas emissions in the European Union of at least 50% and up to 55%. The required PV capacity in the EU would need to be significantly higher than the estimated 360 GW to achieve the 32% Renewable energy systems target in the recast Renewable Energy Directive [10], depending on the chosen pathway to achieve the targeted greenhouse gas reduction and assumptions about the technology availability of alternative options. Turkey's yearly energy demand, particularly that for electricity, is rapidly increasing as a developing country [5]. However, with a small domestic reserve, Turkey is heavily reliant on imported fossils fuel to meet rising demand. As a result, Turkey's current energy policy is oriented towards reducing the amount of fossil fuel imported [11].

In this context, the renewable energy support mechanism (YEKDEM) incentive programs, the first of which started in 2005 [12], have been updated in different periods of time and continue until today. One of these is that a new program was introduced in 2021 with a mathematical relationship that changes depending on the US$, EURO, CPI (Consumer price index), and PPI (producer price index) [13]. There are various support mechanisms to increase the share of renewable energy use around the world. These are mostly in the form of tax deductions, feed-in tariffs for the electricity produced, and financial support [14–17].

The main purpose of this study is to make an evaluation on the solar energy incentive amounts calculated according to the correlation announced within the scope of the YEKDEM support program announced in 2021 (varies depending on CPI, PPI, US$, and EURO) for the 24-month period between July 2021 and 2023. At the same time, it is aimed to make an evaluation of YEKDEM sales prices. The results are presented in tables and necessary comments have been made.

Material and Methods

The organization responsible for implementing Turkey's support mechanisms for renewable energy resources is called YEKDEM. YEKDEM was founded with the intention of increasing the number of industrial facilities through incentives and the utilization of our limitless and clean indigenous energy resources. Increasing the amount of renewable energy, as is well known, drastically lessens reliance on non-renewable energy sources (coal, oil, natural gas, etc.). This improves the quality of life in our universe, especially for the coming generations. YEKDEM was founded in 2005 and continues to operate through its most recent update in 2023. A new formula was announced in 2021 [13] for this purpose, and it was changed once again in 2023 [18]. A decision has been made in the Republic of Turkey about the rates and terms that apply to electricity generation facilities that use renewable energy sources and have a Renewable Energy Resources (YEK) certificate. These facilities begin operating on July 1, 2021, and run until December 31, 2025. (Articles 5346; 6th - 6/B; Law number and decision number: 3453) [13]. YEKDEM in 2021 is given in 3-month periods and is updated every year in January, April, July and October according to the following method. Eq. (1) provides the formula for the YEKDEM-2021 that was announced.

$$YEKDEM_{GD} = YEKDEM_{OGD} x[\left(\frac{26}{100} x \frac{PPI_{A-2}}{PPI_{A-5}}\right) + \left(\frac{26}{100} x \frac{CPI_{A-2}}{CPI_{A-5}}\right) + \left(\frac{24}{100} x \frac{EXC.RATE_{D-A}}{EXC.RATE_{D-B}}\right) + \left(\frac{24}{100} x \frac{EXC.RATE_{E-A}}{EXC.RATE_{E-B}}\right)] \quad (1)$$

The support price in this case is $YEKDEM_{GD}$, which is computed as TL-kurus/kWh for three months. The pricing for the preceding three months (TL-kurus/kWh) is $YEKDEM_{OGD}$. The Domestic Producer Price Index is known as PPI. CPI, is known as Consumer Price Index. The average monthly US$ exchange rate is called EXC. $RATE_D$. The euro (€) exchange rate on a monthly average is called $EXC.RATE_E$. 2. 5, A and B represent the respective months. A-2 represents the second month before the month in which the YEKDEM application system is valid. The Central Bank of the Republic of Turkey releases all processed exchange rates [19].

Results and Discussion

In this study, an evaluation has been made on YEKDEM values calculated according to YEKDEM-2021 between July 2021 and July 2023 for solar energy. The first YEKDEM application starting price valid for solar energy ($YEKDEM_{OGD}$) is analyzed as 32.00 Turkish lira-kurus/kWh, and the results are analyzed to be close to the upper limit value of 5.10 cents US$/kWh. These outputs are presented below. The value of the obtained incentive amounts in TL-kurus/kWh terms is given in Table 1.

Table 1. YEKDEM amounts obtained in TL-kurus/kWh.

	January	April	July	October	Total
2021	-	-	34.62	36.91	71.53
2022	40.76	56.88	65.58	70.12	233.34
2023	75.83	80.98	83.89	-	240.70
GENERAL TOTAL (TL-kurus/kWh)					545.57

Looking at the table, it has been observed that the data increases continuously from the month the application starts to the month it ends. While this increasing rate is minimal for 2021, it reaches its maximum level in 2022 and the increases accelerate slowly in 2023. The reason why the incentive amount increased so much in 2022 is that the CPI, PPI, US$, and EURO values increased unpredictably in 2022. To see these data more clearly, the data of the Central Bank of the Republic of Turkey can be viewed [20]. The sudden increase in data may be thought to have a positive impact on solar energy power plant investors. However, setting the upper limit of incentives as 5.10 cents USD/kWh negatively affects investors after a certain point. Because while the incentive amount is fixed, the general cost of the power plant increases. These situations are generally similar for all developing countries. While the lowest amount is obtained in July 2021 (the first incentive amount given) as 34.62 TL-kurus/kWh, the highest amount is obtained in July 2023 (the last month) as 83.89 TL-kurus/kWh. The incentive amount is calculated as 71.53 TL-kurus/kWh in 2021, 233.34 TL-kurus/kWh in 2022 and 240.70 TL-kurus/kWh in 2023. The total of these three years corresponds to 545.57 TL-kurus/kWh.

As mentioned before, incentive amounts are given to investors in cents US$/kWh. These values are given in Table 2 as cents US$/kWh by the date on which the calculation was made.

Table 2. YEKDEM incentive amounts in cents US$/kWh.

	January	April	July	October	Total
2021	-	-	4.02	4.04	8.06
2022	3.01	3.87	3.77	3.53	14.18
2023	4.04	4.20	3.22	-	11.46
GENERAL TOTAL (cents US$/kWh)					33.70

Here it can be seen that the values vary between 3.01 and 4.20 cents USS/kWh. When compared to the values obtained in terms of TL-kurus per kWh (Table 1), it is understood that there is a fluctuation between the values. The main reason for this is the increase in the dollar when the values obtained in TL are converted into US dollars. As the TL lost a lot of value against the US$, it is observed that although the numbers in TL increased, they decreased in dollar terms. This situation may also put the investor in a difficult situation. But none of the

values reaches the upper limit of 5.10 cents US$/kWh. If some values exceed this limit, the investor receives a fixed amount of only 5.10 cents US$/kWh. The lack of a lower limit value can also be considered a disadvantage for the investor. Because these values may be much lower. According to the 2021 YEKDEM program for the years 2021-2023, the sales prices of electricity produced by solar energy are presented in Table 3 (TL-kurus). The sales price has been calculated by the method made by Gürtürk et al. [21]. Each column represents the average times in that month.

Table 3. Sales prices of electricity for the 2021 YEKDEM program (US$).

2021 July	2021 October	2022 January	2022 April	2022 July	2022 October	2023 January	2023 April	2023 July
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
3.939023	0	0	0.089203	3.939023	0	0	0.089203	2.954268
15.3065	2.987419	0	7.494601	15.3065	2.987419	0	7.494601	11.47988
22.01331	15.85953	1.911621	14.90311	22.01331	15.85953	2.548828	14.90311	16.50998
27.27316	21.97798	10.45023	19.45845	27.27316	21.97798	13.93363	19.45845	20.45487
31.35703	25.56955	13.71678	22.85508	31.35703	25.56955	18.28905	22.85508	23.51777
33.67498	27.18469	15.43467	24.69046	33.67498	27.18469	20.57956	24.69046	25.25624
34.54326	27.19022	15.99874	25.0529	34.54326	27.19022	21.33166	25.0529	25.90745
34.0063	26.36747	15.77119	24.20949	34.0063	26.36747	21.02826	24.20949	25.50473
32.8342	24.76193	14.94952	22.91895	32.8342	24.76193	19.9327	22.91895	24.62565
30.75441	22.09693	13.53336	20.86822	30.75441	22.09693	18.04447	20.86822	23.0658
27.5395	17.81927	10.89502	17.65455	27.5395	17.81927	14.52669	17.65455	20.65463
23.18878	6.769939	2.50969	13.50074	23.18878	6.769939	3.346254	13.50074	17.39159
17.52	0	0	6.662358	17.52	0	0	6.662358	13.14
3.813429	0	0	0.089446	3.813429	0	0	0.089446	2.860072
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

The study is carried out for the Antalya province of the Republic of Turkey. Looking at Table 3, it is understood that the investor's profit rate is high in July, when the radiation value is at its highest, but the investor's profit rate is very low in January due to the low radiation value. These numbers also change depending on CPI, PPI, US$/TL and EURO/TL changes. For example, even when the radiation value is the same or low, it may be high depending on the high YEKDEM result obtained. This situation can be better understood when the data in the table is examined carefully. In this study, when determining sales prices, radiation values are determined assuming that the weather is sunny all year round.

Conclusion

In the current study, an analysis has been carried out on the incentive amounts given to investors between 2021 and 2023 within the framework of the renewable energy support program called YEKDEM, announced in Turkey in 2021. In the light of the study, the results presented below have been obtained.

- The amount of incentives investors receive in the summer months is higher than in other months.

- While the incentive amounts obtained in TL are constantly increasing, there is a fluctuation in the amounts obtained in US dollars.
- Incentive amounts are given as 8.06 cents USS/kWh in 2021, 14.18 cents US$/kWh in 2022, and 11.46 cents US$/kWh in 2023.
- The total incentive amounts given per kWh were found to be 545.57 on a TL-kurus basis and 33.70 on a cents US$ basis.

As a result, considering the country's inflation data in these years and the general cost of the solar power plant, it is thought that the incentive amounts given are not very large figures.

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EFFECT OF ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSIONS ON ECONOMIC GROWTH IN TURKEY: EMPIRICAL EVIDENCE FROM THE AGRICULTURAL SECTOR

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ABSTRACT

The agricultural sector involves intensive energy usage in various stages, including soil cultivation, irrigation, harvesting, and product storage. Thus, planning the energy use in agriculture efficiently is crucial for reducing costs, minimizing environmental impacts, and ensuring the sustainability of agricultural productivity. The aim of this study is to determine the impact of energy consumption and greenhouse gas emissions on growth in Turkey within the agricultural sector between 1998 and 2020. The agricultural gross domestic product data has been used to represent the variable of economic growth in the agricultural sector. Data that represent total energy consumption in the agricultural sector, measured in tera joules for energy consumption, and data indicating total greenhouse gas emissions in the agricultural sector, measured in million tons of CO2 equivalent for carbon emissions, have been utilized. The results of the unit root tests have indicated that the variables used in the model have been stationary at different levels which is I(0) and I(1). Thus, the Autoregressive Distributed Lag Bound Test approach, which has been employed and provides consistent and unbiased results in small samples for series with different levels of stationarity, has been used to examine short and long-term relationships between variables. Moreover, the long term coefficient results indicate that a 1% increase in energy consumption in the agricultural sector corresponds to a 0.24% increase in the agricultural gross domestic product value. Furthermore, the vector error correction model coefficient, which has been calculated as 0.62, indicates that short-term imbalances have been corrected within 1.67 periods. Also, greenhouse gas emissions from the agricultural sector have had a positive and significant impact on agricultural gross domestic product. It has been considered that to reduction of fossil fuel use and increase in renewable energy sources, increase in incentives for the use of high-energy efficiency smart agricultural technologies.

Keywords: Agricultural sector, energy consumption, greenhouse gas emissions, economic growth, ARDL bounds testing approach,

Introduction

The agricultural sector is gaining more importance with the increasing world population. Also, the sector significant that supplies raw materials to the food industry and service sector. Energy consumption, on the other hand, is one of the most important production factors used in the production process of all goods and services today. However, energy usage is a crucial factor with a critical role in economic activity, production, and the environment. With the increasing use of machinery and technology in the agricultural sector, energy consumption is also on the increase consistently. Especially with the transition from traditional farming methods to modern agricultural techniques, energy is needed for numerous processes, which include irrigation, fertilization, tractor usage, harvesting, and cold storage. Thus, the consideration of energy usage in the agricultural sector in terms of sustainability and efficiency is important. Moreover, the increased use of fossil fuels necessitates global measures for environmental issues caused by climate change. In this regard, analyzing the impact of increasing greenhouse gas emissions on the environment along with economic growth becomes essential. Evaluating how agricultural economic growth and increased greenhouse gas emissions will be affected by the growing demand for energy in the agricultural sector forms the fundamental motivation of this study. Determining the degree of factors affecting energy usage in Turkey on a sectoral basis and analyzing their impact on the environment is important. Furthermore, policymakers consider the economic growth and environmental impact of sectoral distributions in determining investment and incentive decisions. Therefore, the distribution of sectoral consumption is important in addition to total energy consumption. For these reasons, energy consumption in the agricultural sector needs to be evaluated both environmentally and economically.

There are numerous studies that investigate the relationship between economic growth, energy consumption, and the environment in the literature. However, assessments need to be examined at the sectoral level, within the framework of individual countries and country groups due to variations in economic structures from country to country and different time periods. Studies explaining the relationship between energy consumption and economic growth have been grouped under specific categories in the literature review. Some studies suggest that energy consumption has no impact on Gross Domestic Product (GDP), while others indicate a unidirectional causality from GDP to energy consumption, and still others suggest a bidirectional effect. Thus, it is not possible to make a definitive inference about the relationship between the two variables. The observed variations are considered to be rooted in differences in the examined periods, regional levels, and levels of economic development. Additionally, the studies show variations in the methodology used, with micro-level and single-country studies employing different time series analyses. Moreover, cointegration analyses, causality tests, and error correction models are prominently featured. Furthermore, panel data analysis methods are preferred. From this perspective, it is possible to categorize the relevant literature into three main groups in studies conducted for country groups.

The relationship between economic growth and energy consumption varies from country to country and across different time periods in studies focusing on a single country. Some studies have identified a unidirectional causal relationship (Shiuand & Lam, 2004; Narayan & Singh, 2007; Odhiambo, 2009; Abosedra, et al., 2014; Alshehry & Belloumi, 2015). On the other hand, a bidirectional causality relationship indicating a mutual relationship between variables has been determined in some of the researchs (Paul & Bhattacharya, 2004; Fuinhas & Marques, 2012; Tang & Tan, 2013; Osigwe & Arawomo, 2015; Arora & Shi, 2016; Rathnayaka, et al., 2018). In a limited number of studies, it has been concluded that the impact of economic growth on energy consumption is consistent with the neutrality hypothesis (Soares, et al., 2014). The first group of studies primarily examines sectoral analyses based on a single country and micro-level data. The relationship between energy consumption and economic growth has been analyzed in the agriculture, industry, service, manufacturing, housing, and transportation sectors in sectoral studies. For instance, Tsani (2010), who conducted Toda-Yamamoto causality tests for the transportation, industry, and housing sectors in Greece between 1960 and 2006, reached different results. According to the study findings, a bidirectional causality relationship has been identified between energy consumption and GDP in the industry and housing sectors. Yet, There has no causality relationship found in the transportation sector. Bernard & Kenneth (2016) have found that the amount of energy consumed in industry, transportation, and housing in Nigeria has had a positive impact on economic growth. Mirza & Kanwal (2017) have investigated the relationship between energy consumption and economic growth in Thailand and Pakistan between 1971 and 2009 using cointegration and ARDL models. The findings have indicated a bidirectional causality relationship between the variables, and long-term cointegration has been confirmed. Fan & Hao (2020) have explored the relationship between economic growth, renewable energy consumption, and foreign direct investments in the Chinese economy from 2000 to 2015. The study result have been identified a unidirectional causality relationship from renewable energy consumption to economic growth. Koç (2020) has investigated the transportation, service, industry, and agriculture sectors for a total of 132 countries from 2010 to 2016. According to the findings obtained using panel data analysis, a positive relationship has been found between the variables in all sectors.

There are numerous studies focusing on country groups that include many countries from the developed and developing country groups in the literature. Energy consumption is considered one of the fundamental elements of development, particularly for countries in the developing country group. In most studies, a relationship between these variables is identified, but different results are obtained regarding the direction of causality. This is thought to be mainly due to the differences in the levels of development among countries and the different evaluation methods selected during distinct time intervals. As an illustration, Le & Chang (2008) identify a unidirectional causality relationship between energy use and GDP in a panel cointegration model for 16 Asian countries during the period 1971-2002. Guvenek & Alptekin (2010) have examined the relationship between energy consumption and economic growth for 25 OECD countries using panel data analysis between 1980 and 2005. The study result conclude that there is a significant relationship between energy consumption and economic growth. Menegaki (2011) have found a weak negative relationship between renewable energy and GDP in selected 25 European countries between 1997 and 2007. Tiwari (2011) has reported the relationship between renewable and non-renewable energy sources with GDP using panel data analysis during the period 1965-2009. The analysis reveale that renewable energy has a positive impact on GDP. Ersoy (2012) has used panel data analysis to analyze real GDP and primary energy consumption variables for OECD countries between 1987 and 2007. The analyses conclude that the variables are cointegrated in the long term. Sebri &

Ben Salha (2014) have investigated the relationship between renewable energy consumption and economic growth in BRICS countries from 1971 to 2010 using the ARDL method. The findings indicate a positive impact of renewable energy consumption on economic growth. Aslan & Ocal (2016) have examined the impact of renewable energy consumption on economic growth for eight Europena Uninon countries from 1990 to 2019 using the ARDL approach. The analyses reveale a positive relationship between energy consumption and economic growth. Kahia et al., (2017) which has conducted panel data analysis for MENA countries from 1980 to 2012, separating energy use into renewable and non-renewable categories. The reseracher have been found that bidirectional causality between both energy types and economic growth. Ballı et al., (2018) have used panel cointegration and causality tests for CIS countries with annual data from 1992 to 2013. The results have been indicated a cointegration relationship between the variables and a positive impact of energy consumption on economic growth. Önder & Polat (2018) examine renewable and non-renewable energy sources for 35 OECD countries between 1996 and 2014. According to the findings, renewable energy sources have been positive effect on GDP, while non-renewable energy sources have been negative effect. Syzdykova (2018) has evaluated the relationship between per capita energy consumption and GDP using panel data analysis for Central Asian countries from 1991 to 2016. The study findings have concluded that there is a bidirectional causality relationship between the variables. Tuğcu & Topcu (2018) have been analyzed the long and short-term relationships between energy consumption and economic growth for G7 countries from 1980 to 2014 using the NARDL method. The findings have been denoted that there has been an asymmetric relationship between the variables in the long term. Erdogan et al., (2020) have found that energy consumption leads to economic growth which concluded using panel data analysis for eight MENA countries from 1990 to 2014. Ateş & Yağcı (2023) have been investigated the impact of energy consumption on economic growth in BRICS countries from 1990 to 2020 using panel data analysis. According to the study results, increase in energy consumption influences economic growth positively. Ayyıldız (2023) has been evaluated the impact of primary energy consumption on economic growth for G-7 countries from 1990 to 2021 using the panel quantile regression method. Study findings revealed that a 1% increase in primary energy consumption leads to a 2.29% increase in economic growth. Bozkaya & Aytekin (2023) have been examined the impact of energy consumption, inflation, and physical and human capital on economic growth for BRICS countries from 1990 to 2015. There has not been found relationship between energy consumption and economic growth according to the findings obtained from panel data analysis.

The literature includes recent studies conducted on Turkey. In the majority of these studies that have identified a causal relationship between energy consumption and economic growth, it has been concluded that there is cointegration between the variables in the long term. To illustrate, Erbaykal (2007) has been investigated the relationship between economic growth and energy consumption using the ARDL boundary test approach for the period 1970-2003. The findings denoted that there is cointegration between the series in the long term. Mucuk & Uysal (2009) have been analyzed the impact of energy consumption on economic growth using cointegration tests for the years 1960-2006. The research findings have indicated that the existence of cointegration between the series in the long term, and a unidirectional causality from energy consumption to economic growth has been identified. Aydın (2010) has been examined the relationship between primary energy sources used in energy consumption and economic growth from 1996 to 2004. Predictions result revealed that changes in energy consumption increase economic growth. Aytaç (2010) has been found a unidirectional causality relationship from energy consumption to economic growth using VAR analysis for the period 1975-2006. Korkmaz & Develi (2012) have been explored the relationship between primary energy usage and GDP using Johansen cointegration and Granger causality tests for the years 1960-2009. The study's findings have been asserted that bidirectional causality between the variables. Çetin & Seker (2012) have been evaluated data from 1970 to 2009 using the Toda and Yamamoto causality test. The study result showed that a positive relationship between energy consumption and economic growth. Şahbaz &Yanar (2013) have been investigated the relationship between total and sectoral energy consumption and GDP for the years 1970-2010. While no causality relationship has been identified in the industry and housing sectors; a unidirectional causality relationship has been found in the transportation and agriculture sectors. Ertuğrul (2013) has been employed a dynamic analysis approach to examine the energy consumption and economic growth relationship for the period 1970-2011. The study has identified cointegration between the variables in the long term. According to Kalman filter analysis, it has been determined that energy consumption had a negative effect on GDP until 2003, which has later turned positive. Tatlı (2015) has been used the ARDL boundary test approach to analyze short and long-term relationships for the years 1981-2013. Both short and long-term total energy consumption have been positively affected economic growth in the study. Lebe & Akbaş (2015) have been

conducted research for the years 1960-2012 using the impact-response analysis method based on FMOLS, DOLS, and SVAR models. The findings indicated structural breaks in the variables and cointegration in the long term. Yanardağ (2016) has been evaluated the energy consumption and economic growth relationship using cointegration and causality analysis methods for the annual data from 1998 to 2012. The findings have been showed that a unidirectional causality relationship from energy consumption to economic growth. Şimşek (2016) has been examined the relationship between total energy consumption and GDP for the years 1990 to 2014. According to the ARDL boundary test results, a unidirectional causality relationship has been identified from total energy consumption to economic growth. Usta (2016) has been used panel data analysis for 26 regions in Turkey from 2004 to 2011 and has found that regional energy consumption has positively influenced growth. Usta & Berber (2017) have been employed panel data analysis for Turkey from 1970 to 2012 and determined a bidirectional causality relationship between energy consumption and economic growth in the industrial sector, while no relationship has been identified in the agricultural and housing sectors. Polat (2017) has been examined the impact of energy consumption on economic growth using FMOLS, DOLS, and CCR methods for the years 1980-2013. The study result revealed that a positive relationship between the variables in the long term. Hanifi & Özen (2018) have been investigated the effect of energy consumption on economic growth in the main sectors of Turkey from 1971 to 2012 using panel data analysis. The findings indicated that a unidirectional relationship between variables in the agricultural and service sectors.

The demand for energy also inreases with the increase in economic growth. Also the consumption of fossil fuels increases along with the growing productionn a global scale. Thus, an increase in greenhouse gas emissions released into the atmosphere is expected in sectors with intensive energy consumption. In this context, where developing countries are taken into consideration, they are still in the early stages of development. It is known that the rapid depletion of natural resources occurs with the increase in production, affecting environmental pollution. However, as economic development advances, technologies that are initially insensitive to the environment are said to evolve over time towards environmentally friendly production structures. During the initial stages of growth, it has been believed that income has increased along with greenhouse gas emissions. Beyond a certain point, income growth is expected to lead to emissions reduction (Grossman & Krueger, 1991). In this regard, considering environmental factors alongside energy consumption is crucial in developing long term economic policies. This study examines the impact of economic growth in the agricultural sector on the environment, specifically through greenhouse gas emissions within this framework. Studies investigating the relationship between economic growth and the environment are predominantly conducted at the country group level using panel data analyses. Another notable finding is that the results of studies examining the relationship between energy consumption and greenhouse gas emissions (CO_2) vary. As evidenced by Apergis et al., (2010) have been examined the relationship between renewable energy consumption, CO_2 emissions, and economic growth for 19 developed and developing countries from 1984 to 2007 using the panel data analysis method. The findings of the study reveale that a positive relationship between CO_2 emissions and renewable energy consumption. Bekun et al., (2019) have been found that economic growth increased CO_2 emissions for 16 EU countries from 1996 to 2014 using panel data analysis. Kaymak (2022) has determined that the causal relationship between total energy consumption, greenhouse gas emissions, and GDP is not valid in the short term from 1990 to 2020. Miçooğulları (2023) has been investigated the causality relationship between carbon emissions and economic growth in Turkey from 1923 to 2018 using an extensive dataset. The study findings denoted that there is a causality relationship from CO_2 emissions to GDP in five different sub-periods, while only one sub-period showe a causality relationship from economic growth to CO_2 emissions. Akadiri & Adebayo (2022) have been analyzed for the period 1970-2018 using the Nonlinear Autoregressive Distributed Lag (NARDL) model in India. The study's results indicate that a positive shock in economic growth positively affect carbon emissions. Some studies focus on environmental issues for various country groups. As an illustration, Yıldırım & Akın (2023) have been examined the impact of renewable and non-renewable energies on CO_2 emissions for 23 OECD countries from 1990 to 2019 using the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model. According to the study findings, a 1% increase in energy intensity, non-renewable energy production, and renewable energy production increased CO_2 emissions by 1.129%, 1.047%, and 0.032% in the long term, respectively. Kazanasmaz et al., (2023) have been investigated the relationship between economic growth, electricity consumption, and carbon emissions in Turkey from 1967 to 2017. Causality test results have been revealed that a unidirectional causality relationship from electricity consumption to economic growth and carbon dioxide emissions. Moreover, the vector error correction model and cointegration analysis results indicate that the long term effect of electricity consumption on economic growth positive. Additionally,

a negative effect of CO_2 emissions on economic growth is determined. Karaca & Çımat (2023) have been examined the impact of per capita energy consumption, industrialization, and GDP on CO_2 emissions in Turkey from 1960 to 2015. The study result emphasize that GDP increases reduce CO_2 emissions, while energy consumption may increase CO_2 emissions, leading to environmental issue. This study dive into four main sections. The first part includes the introduction and literature review. The second section provides detailed information about the econometric method and the data set used, with a focus on literature studies. The third section extensively discusses the empirical findings. The final section presents the conclusions of the study along with possible policy recommendations.

Materials and Methods

This study covers annual data from 1998 to 2020. The agricultural gross domestic product (GDP) and greenhouse gas emissions data utilized in the study have been acquired from the Turkish Statistical Institute database. The GDP data have been categorized according to main economic activities and have been adjusted to real terms using the 2009 base year deflator before being incorporated into the model. The Total Energy Consumption data have been obtained from the International Energy Agency database. The total energy consumption in the agricultural sector has been included in the model in tera joules, and total greenhouse gas emissions have been included in million tons of CO_2 equivalent. The natural logarithms of all variables used in the study have been taken. Definitions of the variables used in the model are shown in Table 1.

Table 1. Variables and Their Descriptions

VARIABLE NAME	ABBREVIATION	SOURCE
Agricultural Gross Domestic Product (TRY)	GDPagricultural	The Turkish Statistical Institute
Total Energy Consumption in Agricultural Sector (Tera Joule)	ENERGYagricultural	International Energy Agency
Greenhouse gas emissions by sectors (CO_2 equivalent-Million tonnes)	GHGagricultural	The Turkish Statistical Institute

Unit root tests are commonly used to determine the stationarity of time series data. The construction of econometric models for time series analysis, the constancy of the mean, variance, and covariance of the relevant series over time indicates that the series is stationary. The use of non-stationary series leads to a spurious regression problem, where there is an assessment of a meaningful relationship between the series in the model. Additionally, the parameters of the model are misinterpreted due to this situation. Thus, it is essential to stationarize the series before including them in the model for the reliability of the estimated parameters (Baltagi, 2003; Gujarati, 2004). In this study, the Augmented Dickey-Fuller (ADF) unit root test has been employed to assess the stationarity characteristics of the series. The null hypothesis in the unit root test suggests that the series is non-stationary and contains a unit root. The stationarity of the series is evaluated with three different models: stationary without trend and intercept, stationary with a intercept, and stationary with a intercept and trend. The equations for the models and the test procedure for the ADF unit root test are given in equations (1), (2), and (3), respectively. Various criteria such as Akaike Information Criterion (AIC) and Schwarz Information Criterion (SC) are used in determining the appropriate lag length for the ADF unit root test. The value that minimizes the lag count according to both information criteria is considered as the optimal lag length.

$$\Delta y_t = \rho y_{t-1} + \sum_{i=1}^{k} \varphi_i \Delta y_{t-i} + \varepsilon_t \quad (1)$$

$$\Delta y_t = \alpha + \rho y_{t-1} + \sum_{i=1}^{k} \varphi_i \Delta y_{t-i} + \varepsilon_t \quad (2)$$

$$\Delta y_t = \alpha + \beta\, t + \rho y_{t-1} + \sum_{i=1}^{k} \varphi_i \Delta y_{t-i} + \varepsilon_t \quad (3)$$

The equation for the model created with the variables used in the study is as follows in equation 4. The dependent variable GDPagricultural represents the value of agricultural gross domestic product, while the independent variables ENERGYagricultural and GHGagricultural represent the total energy consumption and total greenhouse gas emissions in the agricultural sector in equation 4, respectively.

$$GDPagricultural_t = \beta_0 + \beta_1 ENERGYagricultural_t + \beta_2 GHGagricultural_t + \varepsilon_t \quad (4)$$

The ARDL model allows for cointegration testing when the series are stationary at different orders. To put it differently, it is not compulsory for the variables used in the model to be cointegrated at the same level. Moreover, in studies with limited datasets, this method tends to yield more consistent results, which is one of its advantages over other methods. The unrestricted error correction model prepared to determine the impact of energy consumption and greenhouse gas emissions in the agricultural sector on agricultural gross domestic product is given in equation 5 in line with the objective of the study.

$$\Delta lnGDPagricultural_t = \beta_0 + \sum_{k=1}^{m} \beta_{1k} lnGDPagricultural_{t-k} + \sum_{k=1}^{m} \beta_{2k} lnENERGYagricultural_{t-k} + \sum_{k=1}^{m} \beta_{3k} lnGHGagricultural_{t-k} + \beta_4 lnGDPagricultural_{t-1} + \beta_5 lnENERGYagricultural_{t-1} + \beta_6 lnGHGagricultural_{t-1} \quad (5)$$

Symbol Δ represents the difference operator; m denotes the appropriate lag length; β_1, β_2, β_3 represent the error correction coefficients; β_4, β_5, β_6 represent the long-term coefficients; εt represents the error term; k indicates the number of lags for each variable in equation 11. F-test statistic is utilized to determine the existence of cointegration in the model. The null hypothesis tests for no cointegration ($H_0 = \beta_4 = \beta_5 = \beta_6 = 0$; No cointegration), while the alternative hypothesis tests for cointegration ($H_1 = \beta_4 \neq \beta_5 \neq \beta_6 \neq 0$; Cointegration exists).

The calculated F-statistic value is compared with lower and upper critical values to assess the presence of cointegration. If the calculated F-statistic value is less than the lower critical value provided in the studies by Pesaran et al. (2001), it is inferred that there is no cointegration among the series; if it is greater than the upper critical value, it is concluded that there is cointegration among the series. On the other hand, if the calculated F-statistic value falls between the lower and upper bounds, a definitive decision cannot be made regarding the presence of cointegration. After identifying the cointegration relationship for the long term, the short-term coefficients are estimated using the error correction model (ECM). The ECM is expressed in equation 6.

$$\Delta lnGDPagricultural_t = \beta_0 + \sum_{k=1}^{m} \beta_{1k} lnGDPagricultural_{t-k} + \sum_{k=1}^{m} \beta_{2k} lnENERGYagricultural_{t-k} + \sum_{k=1}^{m} \beta_{3k} lnGHGagricultural_{t-k} + \varphi ECT_{t-1} + \varepsilon_t \quad (6)$$

The coefficient of the parameter φ, indicating the speed at which variables converge in the long run, is expected to be negative and statistically significant. The natural logarithm of all data is included in the analysis. The calculated coefficients have been interpreted as elasticity values for the variables. Critical values determined by Pesaran et al. (2001) have been used for predictions with the ARDL model. Eviews 12 software has been employed for model estimations.

4.Findings and Discussions

The stationarity and cointegration degrees of the series have been determined before estimating the ARDL model in the study. For this purpose, the Augmented Dickey Fuller (ADF) unit root test has been employed for all series. The results of the Augmented Dickey Fuller (ADF) unit root test statistics are presented in Table

2. According to the unit root test statistics, it has been found that the first difference of the GDPagricultural variable has become stationary when taken in models containing intercept, trend, and intercept at a 5% significance level.

The stationarity levels of the independent variables ENERGYagricultural and GHGagricultural have been determined to be I(0) and I(1). While the ENERGYagricultural variable has been stationary at the level in the model containing intercept, it has become stationary when the first difference is taken in the trend and intercept model. On the other hand, GHGagricultural variable has become stationary after taking the first difference in the model containing intercept but has become stationary both at the level and when the first difference is taken in the trend and intercept model. Since variables have been stationary at different levels, ARDL boundary test approach have been conducted next part of the study.

The maximum lag length in the ARDL model has been set to 4 since the data used in the study are annual. Also, the most suitable ARDL model has been selected using the Schwarz information criterion. Moreoever, the analysis results indicate that the most suitable model is the ARDL (2,0,0) model.

Table 2. Augmented Dickey Fuller (ADF) Unit Root Test Results

VARIABLE NAME	INTERCEPT			TREND AND INTERCEPT		
	Test Statistics		Decision of Stability	Test Statistics		Decision of Stability
	Level I(0)	First Difference I(1)		Level I(0)	First Difference I(1)	
Ln(GDPagricultural)	0.377 (0.977)	-7.567*** (0.000)	I(1)	-2.311 (0.408)	-7.799*** (0.000)	I(1)
Ln(ENERGYagricultural)	-6.323*** (0.000)	-1.767 (0.381)	I(0)	-0.883 (0.925)	-4.809** (0.011)	I(1)
Ln(GHGagricultural)	0.920 (0.993)	-3.152** (0.049)	I(1)	-5.653*** (0.003)	-3.593* (0.056)	I(0) I(1)

(**Notes:** ***, ** and * indicate significance at the 1%,5% and 10%level, respectively. The lag order determine using the Schwartz information criterion and the maximum delay length set to 9 mumbers. Values in parentheses denote degree of stability) (**Source:** Author's own computation Using E-view 12)

Table 3 presents the results of the ARDL boundary test approach for cointegration analysis. The calculated F-statistic and relevant critical values for the ARDL model are provided in Table 3. The calculated F-statistic in the ARDL model is greater than the upper critical value at a 5% significance level; thus, the null hypothesis (H_o) is rejected. Consequently, there is evidence of a long term cointegrating relationship between GDPagricultural and the ENERGYagricultural and GHGagricultural variables. In a different manner, the variables move together in the long run.

Table 3. ARDL Bound F-Test Results for Cointegration

Dependent Variable: ln(GDPagricultural)				
			Bound Critical Values	
F Statistic Value	k	Significance Level	Lower Bound I(0)	Upper Bound I(1)
4.992**	2	10%	2.915	3.695
		5%	3.538	4.428
		1%	5.155	6.265

(**Note:** ***, ** and * indicate significance at the 1%, 5%, and 10% level, respectively. The critical values for the lower I(0) and upper I(1) bounds are obtain from Pesaran et al. (2001), Appendix: Case II (**Source:** Author's own computation Using E-view 12).

Table 4 presents the results of short and long-term coefficient estimates and findings related to diagnostic tests. Examining the diagnostic test results of the model, it is inferred that there is no autocorrelation in the model according to the Breusch-Godfrey Serial Correlation LM Test results; there is no changing variance in the model according to the White Heteroscedasticity Test test results; the model is correctly specified based on the Ramsey Reset Test results; and the assumption of normal distribution of the error term is valid according to the Jarque-Bera Normality test results.

Table 4. Long-Run and Short Run Coefficients Using the ARDL (2, 0, 0) Approach

LONG-RUN COEFFICIENTS				
Dependent Variable: Δln(GDPagricultural)				
Independent Variables	Coefficient	Standart Deviation	t-Statistic	Prob. Values
Constant	12.449***	1.147	10.847	0.000
ln(ENERGYagricultural)	0.242**	0.101	2.394	0.029
ln(GHGagricultural)	0.755***	0.083	9.038	0.000

SHORT RUN COEFFICIENTS				
Variables	Coefficient	Standart Deviation	t-Statistic	Prob. Values
Δln(GDPagricultural)-1	-0.199	0.152631	-1.304856	0.2104
ECM(-1)	-0.616***	0.126688	-4.869835	0.0002

DIAGNOSTIC TESTS		
	F Statistic	Prob. Values
Jargue-Bera Normality Test	0.072	0.964
Breusch–Godfrey Serial Correlation LM Test	0.001	0.966
White Heteroscedasticity Test	0.888	0.563
Ramsey Reset Test	0.661	0.428

(**Note:** ***, ** and * indicate significance at the 1%, 5%, and 10% level, respectively. Diagnostic tests results are based on F-statistic. (**Source:** Author's own computation Using E-view 12)

In addition to diagnostic tests, it has been determined that ENERGYagricultural and GHGagricultural variables move in the same direction as GDPagricultural in the long term in the agricultural sector in Turkey according to the obtained cointegration findings. To put it differently, an increase in energy consumption in the agricultural sector leads to an increase in agricultural growth. According to the long-term coefficient results, when ENERGYagricultural increases by 1%, GDPagricultural increases by 0.24%. This result is consistent with findings from studies by Tiwari (2011), Çetin & Seker (2012), Şahbaz & Yanar (2013), Sebri & Ben-Salha (2014), Tatlı (2015), Aslan & Öcal (2016), Polat (2017), Bernard & Kenneth (2016), Ballı et al., (2018), Koç (2020), Ateş & Yağcı (2023).

Moreover, it has been also found that the GHGagricultural variable has a positive and significant effect on GDPagricultural. Furthermore, an increase of 1% in GHGagricultural is determined to increase GDPagricultural by 0.75%. This finding is consistent with the results obtained from studies reporting a positive effect between GHGagricultural and GDPagricultural (Akadiri & Adebayo, 2022; Yıldırım & Akın, 2023; Kazanasmaz et al., 2023).

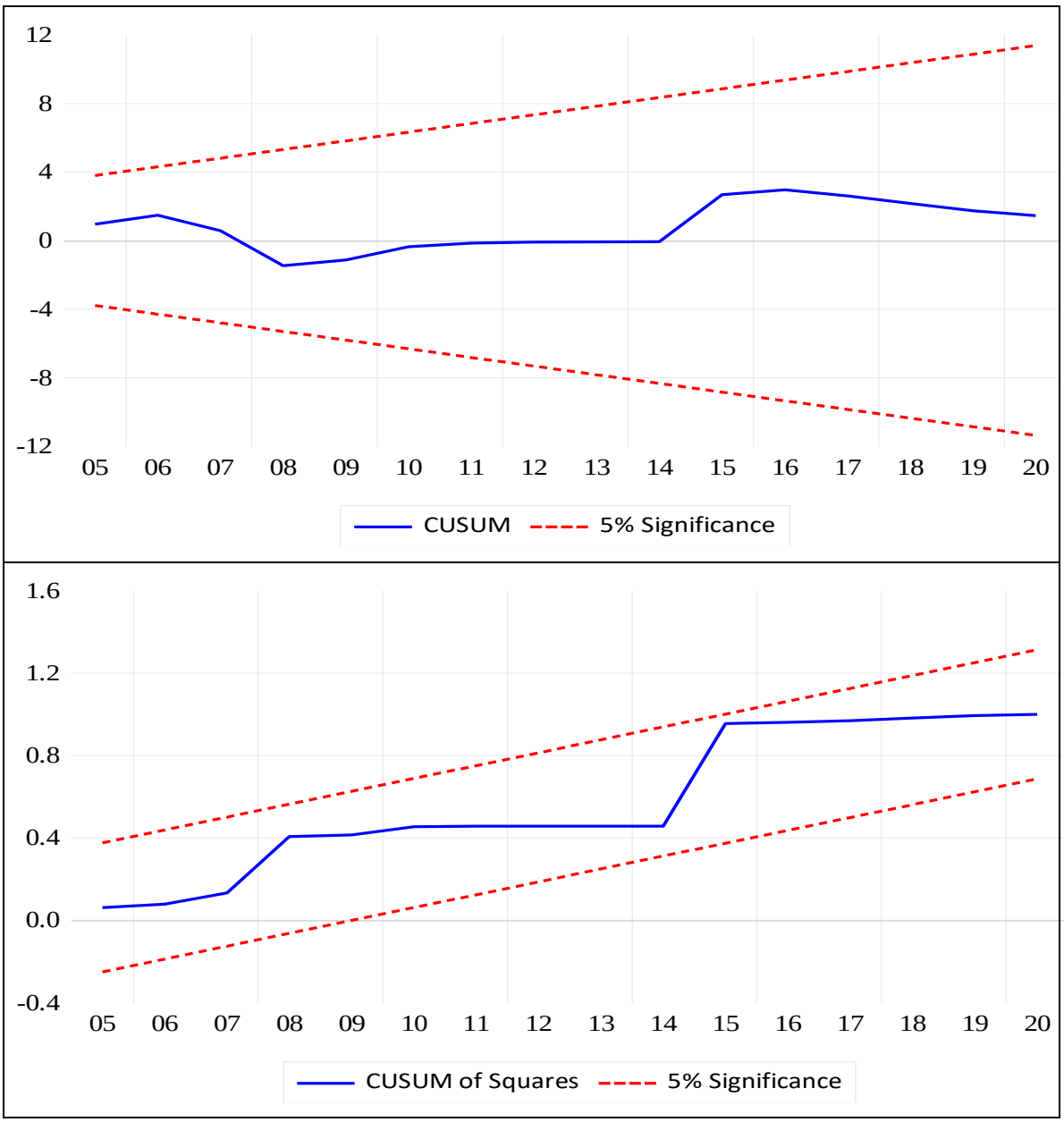

Figure 1. Plot of Cumulative Sum of Recursive (CUSUM) Residuals and Cumulative Sum of Square of Recursive CUSUMQ Residuals

(**Note:** The straight blue lines represent critical bounds at 5% significance level)

(**Source:** Author's own computation Using E-view 12)

After the long-term analysis, which aimed to identify short-term relationships between variables, the calculation of the error correction model coefficient ECM(-1) is required. The error correction term ECM(-1) coefficient (-0.92) has been estimated as negative and statistically significant at the 1% significance level in line with theoretical expectations. This result indicates that short-term imbalances in the model will return to equilibrium in 1.67 periods (1/0.62). In order to assess the stability and reliability of the model, CUSUM and CUSUM-SQ tests, which were proposed by Brown, Durbin, and Evans (1975), have been employed. The results of the CUSUM and CUSUM-SQ tests have been presented in Figure 1. In the model where GDPagricultural serves as the dependent variable, the movement of parameters within the specified limits at the 5% significance level has indicated the stability of the estimated coefficients in the model.

Conlusion and Recommendations

The need for nutrition is growing, and the importance of the agricultural sector plays a critical role in sustainable food production and global food security with the increasing world population. Although energy usage occurs most intensively in the industrial sector, it is also a crucial input for agriculture and other sectors. Moreover, agricultural activities involve a series of energy intensive processes from planting seeds to harvesting crops. Furthermore, the demand for energy in the agricultural sector has increased with the rise in the use of machinery, especially with the adoption of modern farming techniques over conventional ones, which has led to the widespread use of technology and machinery. Besides, the agricultural sector is interconnected with numerous industries such as food, textiles, chemicals, and tourism. Consequently, energy consumption in the agricultural sector is on the increase. Similar to other sectors, energy use in the agricultural sector plays a critical role in agricultural sustainability and environmental issues. Especially in developing countries, where the demand for energy is increasing, the environmental impact of greenhouse gas emissions associated with the use of fossil fuels becomes more pronounced. Thus, there is a need for sustainable and environmentally friendly agricultural policies that promote agricultural growth while controlling greenhouse gas emissions, mitigating environmental impacts, and prioritizing energy efficiency. This study has investigated the short and long-term relationship among energy consumption, greenhouse gas emissions, and agricultural growth in the agricultural sector in Turkey. Energy consumption in the agricultural sector has been examined in harmony with environmental factors, sustainability, and growth objectives in line with this objective. Annual data for the period 1998-2020 have been utilized in the study, and logarithmic transformations have been applied to all series. The agricultural gross domestic product (GDP) value has been employed as an indicator of economic growth in the agricultural sector. Also, total energy consumption in the agricultural sector, which is measured in tera joules, has been added to the model as an indicator of energy consumption. Moreover, total greenhouse gas emissions from the agricultural sector, which is measured in million tons, have been used as an indicator of greenhouse gas emissions. the investigation has focused on whether the variables contain unit roots by applying Augmented Dickey-Fuller (ADF) unit root tests to each variable in this context. To determine the short and long-term relationships between variables identified as stationary at different levels, the Autoregressive Distributed Lag (ARDL) boundary test approach and the Vector Error Correction Model (VECM) have been employed.

As a result of the study a cointegration relationship has been identified between energy consumption and agricultural GDP in the agricultural sector in Turkey according to the findings of the ARDL boundary test approach in the long run. When energy consumption in the agricultural sector increases by 1%, the agricultural gross domestic product (GDP) value increases by 0.24%. The short-term error correction coefficient has been found to be negative and statistically significant. This result indicates that the error correction mechanism is operating. To put it differently, short-term imbalances are corrected within 1.67 periods. Moreover, it has been determined that greenhouse gas emissions in the agricultural sector have a positive and significant impact on agricultural GDP. The effect of greenhouse gas emissions on agricultural GDP is noteworthy. When examining the long-term findings, it has been concluded that a 1% increase in greenhouse gas emissions leads to a 0.75% increase in agricultural GDP. Also, the results of the study indicate that greenhouse gas emissions affect agricultural GDP more than energy consumption. As a result, it is considered necessary to reduce the use of fossil fuels in agricultural production and increase the emphasis on environmentally friendly renewable energy sources. Furthermore it is suggested to enhance incentives for the use of smart agricultural technologies in the agricultural sector; promote the widespread use of energy-efficient buildings, machinery and equipment; implement energy management systems to optimize energy use, and organize national education programs on energy efficiency.

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SEÇİLMİŞ AVRUPA ÜLKELERİ'NDE KARBONDİOKSİT GAZI EMİSYONU VE PETROL TÜKETİMLERİ ARASINDAKİ İLİŞKİ: DOĞRUSAL OLMAYAN ARDL MODELLERİNDEN KANITLAR

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ÖZET

Küresel iklim krizinin derinleşmesiyle birlikte birçok gelişmiş ve gelişmekte olan ülke iklim kriziyle mücadelede önemli adımlar atmaya başlamıştır. Özellikle gelişmiş ülkelerin çoğu küresel iklim kriziyle başa çıkmak için çeşitli anlaşmalar imzalamış çeşitli tedbirler almaya başlamışlardır. Çalışmamız fosil enerji kaynaklarından olan ve Dünya'da en çok ticareti yapılan emtialarından olan petrol ve karbondioksit gazı emisyonu arasındaki ilişkiyi incelemek üzerine kurulmuştur. Analizimizde karbondioksit gazı emisyon değeri en yüksek olan 13 Avrupa ülkesi ve bu ülkelerin petrol tüketimleri ele alınmıştır. Analize konu olan Avrupa ülkeleri; Almanya, Belçika, Çek Cumhuriyeti, Danimarka, Fransa, Hollanda, İngiltere, İspanya, İsveç, İtalya, Macaristan, Polonya ve Romanya'dır. Veri seti olarak 1965-2022 yılları arasındaki en güncel ve en uzun zaman aralığı incelemeye alınmıştır. Karbondioksit emisyon verileri milyon ton olarak, petrol tüketim verileri de milyon ton olarak ele alınmıştır. Analize dahil edilen Avrupa ülkelerinin karbondioksit gazı emisyonu ile petrol tüketimleri arasındaki ilişki doğrusal olmayan eşbütünleşme testlerinden olan Shin, Yu ve Greenwood-Nimmo'nun (2014) literatüre kazandırdığı doğrusal olmayan gecikmesi dağıtılmış model NARDL ile incelenmiştir. Analize konu alınan ülkeler için bazılarının petrol tüketimi ile karbondioksit gazı arasında uzun dönemli ilişki tespit edilememişken bazılarında ise uzun dönemli bir ilişki tespit edilmiştir. Doğrusal olmayan gecikmesi dağıtılmış model NARDL sayesinde modellerin uzun dönem pozitif ve negatif katsayılar hesaplanmış olup bu katsayıların istatistiksel olarak anlamlılıkları da tespit edilmiştir. Ayrıca kısa dönemli asimetrik katsayılar da hesaplanıp analiz zenginleştirilmiştir. Avrupa ülkeleri için Almanya, Belçika, Danimarka ve Fransa gibi sanayileşmesi yüksek olan bazı ülkelerin karbondioksit emisyonları ve petrol tüketimleri arasında uzun dönemli bir eşbütünleşme ilişkisi tespit edilmiştir. Sanayileşme ve ekonomik gelişmişlik düzeyi olarak lider ülkelerin gerisinde kalmış bazı ülkeler için de karbondioksit emisyonları ve petrol tüketimleri arasında uzun dönemli bir ilişki tespit edilememiştir.

Anahtar Kelimeler: Karbondioksit emisyonu, NARDL, Eşbütünleşme, Yakınsama

ABSTRACT

With the deepening of the global climate crisis, many developed and developing countries have started to take important steps to combat the climate crisis. Most of the developed countries have signed various agreements and started to take various measures to cope with the global climate crisis. Our study is based on analyzing the relationship between oil, which is one of the fossil energy sources and one of the most traded commodities in the world, and carbon dioxide gas emissions. In our analysis, 13 European countries with the highest carbon dioxide gas emission value and the oil consumption of these countries are considered. The European countries subject to the analysis are; Germany, Belgium, Czech Republic, Denmark, France, France, Netherlands, UK, Spain, Sweden, Italy, Hungary, Poland, Poland, and Romania. The most recent and longest period between 1965 and 2022 is analyzed as a data set. Carbon dioxide emission data are considered in a million tonnes and oil consumption data in a million tonnes. The relationship between carbon dioxide gas emissions and oil consumption of the European countries included in the analysis is analyzed with the non-linear lagged distributed model NARDL, which is one of the non-linear cointegration tests introduced to the literature by Shin, Yu, and Greenwood-Nimmo (2014). For the countries analyzed, no long-run relationship was found between oil consumption and carbon dioxide gas in some countries, while a long-run relationship was found in others. Long-run positive and negative coefficients of the models have been calculated and statistical

significance of these coefficients has been determined by the nonlinear lag distributed model NARDL. Short-run asymmetric coefficients are also calculated to enrich the analysis. For European countries, a long-run cointegration relationship was found between carbon dioxide emissions and oil consumption of some industrial leaders such as Germany, France, Denmark and France. For some countries that lag behind the leading countries in terms of industrialization and economic development, no long-run relationship was found between carbon dioxide emissions and oil consumption.

Keywords: Carbon dioxide emission, NARDL, Cointegration, Convergence

Giriş

Günümüzün en önemli çevresel kaygılarından biri, iklim değişikliği ve nüfusun yaşam standartları üzerindeki sonuçları nedeniyle ozon tabakasının incelmesi ve küresel ısınmadır. Karbondioksit emisyonları (CO2) büyük ölçüde fosil yakıt tüketimi ve ormansızlaşma sebebiyle yayılan insan kaynaklı sera gazı olup ayrıca bu türden sera gazı emisyonlarındaki artış, iklim değişikliği ve kirlilik gibi iki ciddi tehdide yol açmıştır (Aslam vd., 2021).

Bu ilgi de ekonomistler tarafından geniş çaplı ampirik araştırmalar yapılmasına yol açmıştır. En aktif araştırma alanlarından biri, muhtemelen CO2 emisyonlarının ülkeler arasında zaman içinde azalıp azalmadığını inceleyen araştırmadır. Aslında, fosil yakıt kaynaklarından kaynaklanan karbondioksit emisyonlarının boyutu, bir ülkenin ekonomik yapısına ve doğal kaynak donanımına bağlıdır. Dolayısıyla iklim değişikliğinin en önemli sebeplerinden biri olan CO2 emisyonu ve bu değeri ortaya çıkaran enerji kaynakları ile ilgili ilişkilerin ele alındığı birçok çalışma yapılmaktadır. Bu çalışmada fosil yakıtlardan olan petrolün tüketimi ile CO2 emisyon değeri arasındaki ilişkiyi doğrusal olmayan ARDL eşbütünleşme testi ile incelenmiştir. İncelenen ülke grubu olarak da CO2 emisyon değeri en yüksek 13 Avrupa ülkesi belirlenmiştir. Literatür tarandığında ise tek başına petrol tüketimi ile CO2 emisyonu arasındaki ilişkinin incelendiği çalışmalara çok fazla rastlanılmamıştır. Daha çok incelenen bu iki değişkenle birlikte bunların ekonomik büyüme üzerindeki etkilerinin incelendiği çalışmaların daha yoğunlukta olduğu tespit edilmiştir. Söz konusu değişkenlerin incelendiği çalışmalara ait literatür aşağıdaki gibi özetlenmeye çalışılmıştır.

Al-Mulali (2011), 1980-2009 döneminde petrol tüketimi ve CO2 emisyonunun MENA ülkelerindeki ekonomik büyümesi üzerindeki etkisi nedensellik ve eşbütünleşme testleri ile sınamıştır. Analiz sonuçlarından, ilgili değişkenlerin ekonomik büyüme üzerinde uzun dönemli bir ilişkisi olduğu ayrıca incelenen üç değişken arasında ise çift yönlü bir nedensellik ilişkisi elde edilmiştir.

Lim vd. (2014), 1965-2012 dönemi için zaman serisi teknikleri ve yıllık veriler kullanarak Filipinler'de petrol tüketimi, CO2 emisyonları ve ekonomik büyüme arasındaki ilişki hata düzeltme modeline dayalı nedensellik ve eşbütünleşme testleriyle araştırmışlardır. Analiz sonuçlarından petrol tüketimi ve ekonomik büyüme ile petrol tüketimi ve CO2 emisyonları arasında çift yönlü nedensellik ve CO2 emisyonu ile ekonomik büyüme arasında tek yönlü nedensellik ilişkisi bulunmuştur.

Bildirici ve Bakırtaş (2016), BRICTS ülkelerinde karbondioksit (CO2) emisyonları, ekonomik büyüme, kömür ve petrol tüketimi arasındaki ilişkiyi 1969-2011 dönemi için ARDL kullanarak analiz etmişlerdir. ARDL analizi sonuçlarına göre, seçilen değişkenler arasında kısa ve uzun dönemli ilişkiler tespit edilmiştir. Ampirik sonuçlara göre, analiz edilen ülkelerde ekonomik büyüme ve kömür tüketiminden CO2 emisyonuna ve Çin, Hindistan, Türkiye ve Güney Afrika'da petrol tüketiminden CO2 emisyonuna tek yönlü nedensellik ve Brezilya ve Rusya'da ise çift yönlü nedensellik kanıtları bulunmaktadır.

Hepektan ve Sertkaya (2016), 1980-2014 dönemi için Türkiye'de, kişi başı elektrik tüketimi ve GSYİH, CO2 emisyonu ve petrol tüketimi arasındaki ilişkiyi eşbütünleşme ve nedensellik testleriyle incelemişlerdir. Analizden elde edilen bulgulardan incelenen üç değişkenden elektrik tüketimine tek yönlü bir nedensellik tespit etmişlerdir.

Bildirici (2017), MENAP ülkelerindeki petrol tüketimi ve üretimi, CO2 emisyonu ve GSYİH arasındaki ilişkiyi nedensellik, sınır testi yaklaşımı ve ANOVA yöntemlerini kullanarak incelemiştir. Toda ve Yamamoto nedensellik sonuçlarına göre Bahreyn, Mısır, Fas, Umman, Suriye ve Tunus için GSYİH'den CO2 emisyonlarına ve Pakistan ve Yemen için CO2 emisyonlarından GSYİH'ye tek yönlü; Ürdün, Kuveyt, Lübnan ve Katar için ise çift yönlü nedensellik bulunmuştur.

Çevik vd. (2017), 1996-2011 dönemi için OECD ülkelerinde karbondioksit emisyonu, petrol tüketimi ve petrol fiyatları arasındaki ilişkiyi sanayi sektörü için panel vektör hata düzeltme modelleri kullanarak analiz etmişlerdir. Analiz bulgularından, uzun dönemde petrol tüketimindeki artışın karbondioksit emisyonu üzerinde pozitif bir etki yarattığını göstermişlerdir.

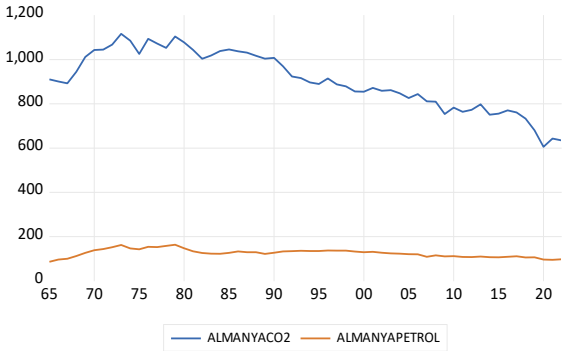
Saboori (2017), petrol ithal eden üç Doğu Asya ülkesinde (Çin, Güney Kore ve Japonya) 1980-2013 dönemi için petrol tüketimi, ekonomik büyüme ve CO2 emisyonu arasındaki ilişkiyi nedensellik, eşbütünleşme, Genelleştirilmiş Etki Tepki fonksiyonları ve varyans ayrıştırma metodu kullanarak analiz etmişlerdir. Analiz sonuçlarından Çin ve Japonya'da petrol tüketiminden ekonomik büyümeye ve Güney Kore'de ise petrol tüketiminden CO2 emisyonlarına tek yönlü nedenselliğe dair bulgulara ulaşılmıştır.

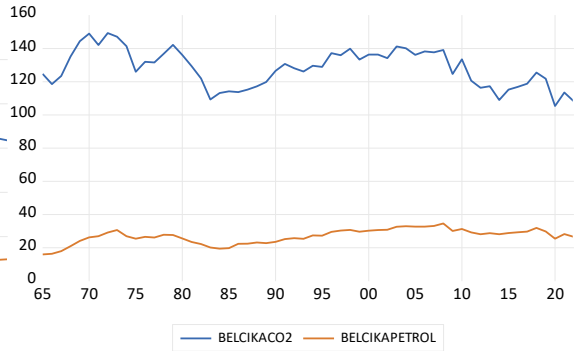
Bunnag (2021), 1971-2014 döneminde Tayland için CO2 emisyonu, petrol tüketimi ve ekonomik büyüme arasındaki ilişkiyi ARDL ve nedensellik yaklaşımları kullanarak incelemiştir. Analiz sonuçlarından elde edilen bulgular CO2 emisyonu, petrol tüketimi ve ekonomik büyüme arasında uzun dönemli bir ilişki olduğuna işaret etmiştir. Ayrıca, petrol tüketimi ile CO2 emisyonu arasında tek yönlü bir kısa dönem nedensellik ilişkisi, petrol tüketimi ve CO2 emisyonu arasında tek yönlü uzun dönem nedensellik ilişkisi ve petrol tüketiminden ekonomik büyüme ve CO2 emisyonuna doğru ise tek yönlü uzun dönem nedensellik ilişkisi bulunmuştur.

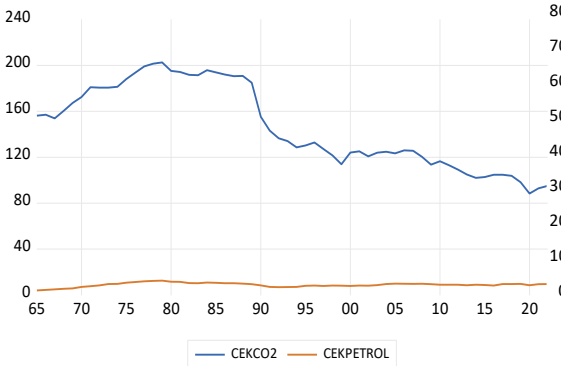
Türköz (2022), 1987-2020 dönemi için Türkiye'nin petrol fiyatları ve tüketimi ile CO2 emisyonu arasındaki ilişkiyi asimetrik nedensellik analizi ile araştırmıştır. Analiz sonuçlarından CO2 emisyonunun hem petrol fiyatları hem de petrol tüketimi ile ilişkili olduğuna ulaşmıştır.

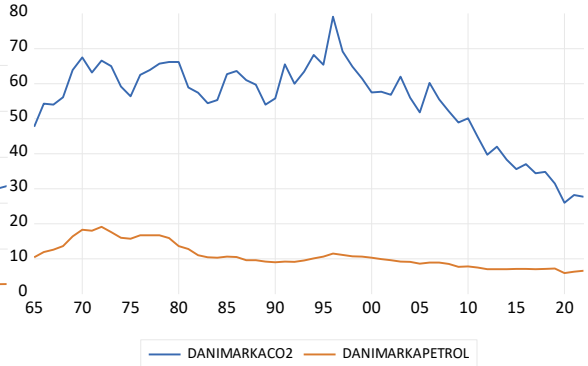
Veri ve Yöntem

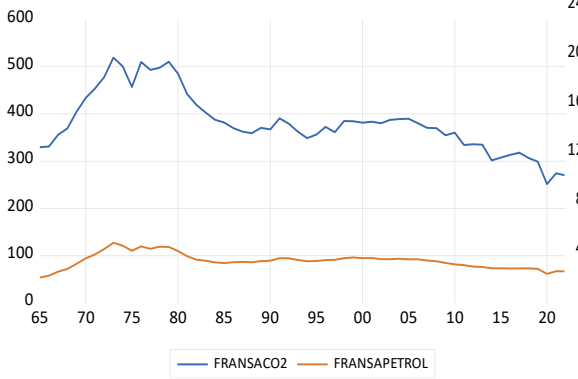
Karbondioksit emisyon verileri ile petrol tüketim verileri British Petrol (BP)'ün yayınladığı enerji raporlarından (BP-Statistical Review of World Energy Haziran-2022) alınmıştır. Ülkelere ait karbondioksit emisyon ve petrol tüketim değerleri milyon ton cinsinden ifade edilmektedir. 1965-2022 yılları arasını kapsayan veri seti için her bir ülkeye ait toplam 58 adet gözlem bulunmaktadır. Karbondioksit emisyonu ile petrol tüketimi arasındaki ilişkinin incelendiği bu çalışmada ülkeler en yüksek CO2 emisyon değerine sahip 13 Avrupa ülkesinden oluşmaktadır. Veri seti için kullanılan karbondioksit emisyon değerleri fosil yakıt tüketiminden kaynaklanan karbondioksit emisyon değerlerini göstermektedir. Aşağıda gösterilen şekillerde ülkelerin karbondioksit emisyon değerleri ile petrol tüketim değerlerine ait grafikler verilmiştir. Grafiklerden de anlaşılacağı üzere çoğu ülkenin karbondioksit emisyon değerleri zaman içerisinde düşme eğilimindeyken petrol tüketim değerleri ise genellikle belirli bir ortalama etrafında salınım yaptığı görülmektedir.







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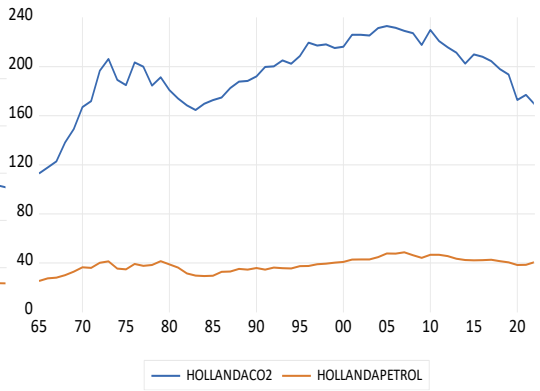
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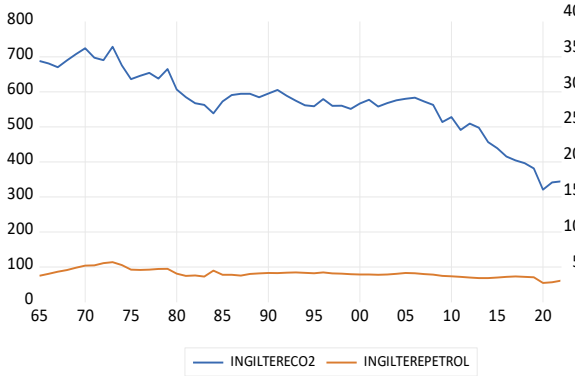
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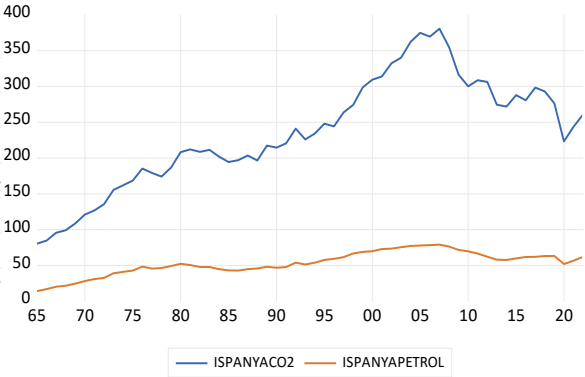
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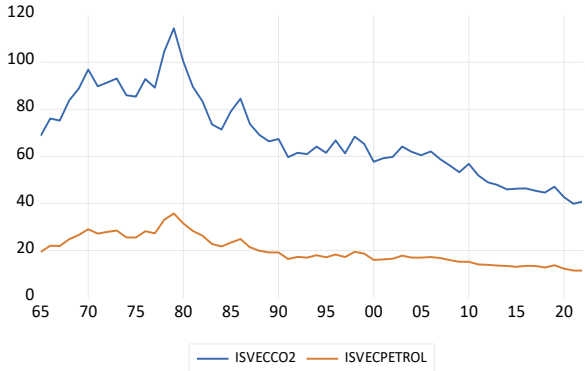
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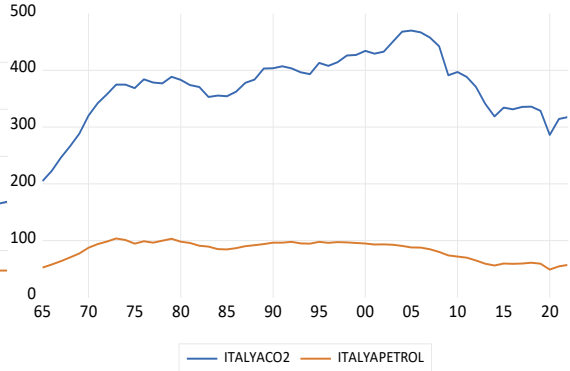
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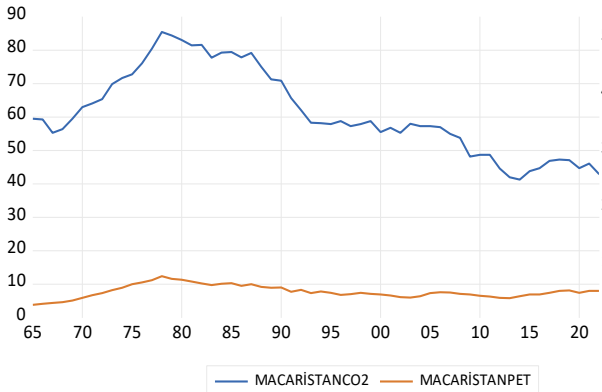
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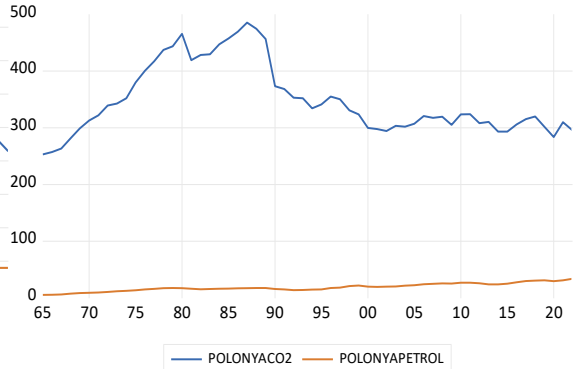
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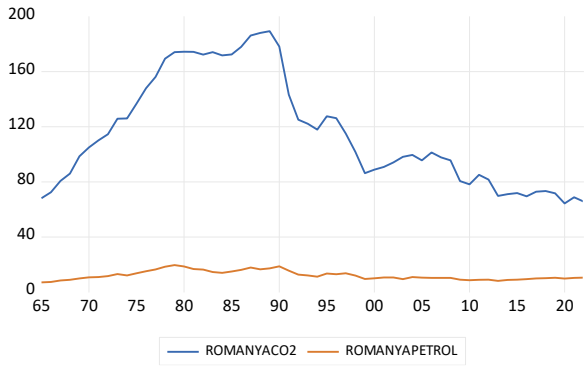

Şekil 1. Ülkelere ait karbondioksit emisyonu ve petrol tüketim değerleri

Mavi renkle gösterilen çizginin ilgili ülkenin karbondioksit emisyon değerini ifade ederken turuncu renkle gösterilen ise ilgili ülkenin petrol tüketim verisini ifade etmektedir. Ülkelerin karbondioksit emisyon oran grafikleri incelendiğinde genellikle 2000'li yılların başlarına kadar sürekli yükselme eğiliminde oldukları 2000'li yıllardan itibaren ise bazı ülkelerin karbondioksit emisyonlarının düşme eğilimine girdikleri ifade edilebilir. Almanya, Danimarka, Fransa, İtalya, İspanya bu duruma örnek olarak gösterilebilmektedir. Petrol tüketim grafikleri incelendiğinde ise çoğu ülke için ciddi bir azalma veya artma trendi gözlenememektedir.

Tablo 1. Ülkelere ait CO2 emisyon değerlerinin tanımlayıcı istatistikleri

Ülkeler	Ortalama	Medyan	Std. Hata	Çarpıklık	Basıklık	J-B Test Değ.	J-B Olasılık
Almanya	907.16	898.98	132.50	-0.31	2.18	2.56	0.28
Belçika	128.20	129.16	11.29	-0.11	2.04	2.36	0.31
Çek Cum.	146.29	133.48	36.16	0.18	1.54	5.48	0.06
Danimarka	54.95	57.46	11.90	-0.85	3.03	7.06	0.03
Fransa	381.40	371.52	62.64	0.49	2.92	2.31	0.32
Hollanda	194.06	199.86	28.47	-0.95	3.71	9.94	0.01
İngiltere	567.32	575.18	96.55	-0.71	3.25	5.05	0.08
İspanya	235.46	230.08	77.27	-0.11	2.35	1.14	0.56
İsveç	68.34	64.75	17.80	0.45	2.47	2.66	0.26
İtalya	371.64	377.66	57.67	-0.70	3.62	5.72	0.06
Macaristan	61.36	58.24	12.72	0.31	1.99	3.37	0.19
Polonya	347.82	323.80	61.97	0.79	2.46	6.78	0.03
Romanya	115.24	101.52	40.03	0.52	1.88	5.62	0.06

Tablo 2. Ülkelere ait petrol tüketim değerlerinin tanımlayıcı istatistikleri

Ülkeler	Ortalama	Medyan	Std. Hata	Çarpıklık	Basıklık	J-B Test Değ.	J-B Olasılık
Almanya	125.11	126.30	17.90	0.08	2.47	0.75	0.69
Belçika	26.88	27.50	4.34	-0.62	2.88	3.81	0.15
Çek Cum.	8.89	9.00	1.81	-0.55	3.48	3.48	0.18
Danimarka	10.79	10.00	3.52	0.84	2.66	7.13	0.03
Fransa	89.03	89.40	16.13	0.26	2.96	0.66	0.72
Hollanda	38.39	38.65	5.54	-0.26	2.51	1.24	0.54
İngiltere	81.28	80.15	11.86	0.57	3.78	4.68	0.09
İspanya	53.13	53.05	16.22	-0.46	2.74	2.23	0.33
İsveç	19.97	18.15	5.95	0.66	2.55	4.67	0.09
İtalya	83.15	90.30	16.22	-0.72	2.00	7.36	0.03
Macaristan	7.77	7.40	1.92	0.31	2.75	1.09	0.58
Polonya	18.71	17.35	6.94	0.13	2.41	0.99	0.61
Romanya	12.13	10.80	3.27	0.67	2.31	5.46	0.07

Ülkelere ait karbondioksit emisyon ve petrol tüketim değerlerinin tanımlayıcı istatistikleri yukarıdaki tablolarda gösterilmiştir. Karbondioksit emisyonunda en yüksek ortalamaya sahip ülke Almanya iken en düşük ortalamaya sahip ülke ise Danimarka'dır. Petrol tüketim değerleri incelendiğinde ise en yüksek ortalamaya sahip ülkenin Almanya, en düşük ortalamaya sahip ülkenin ise Macaristan olduğu tespit edilmiştir. Normal dağılım istatistikleri incelendiğinde ise karbondioksit emisyon değerlerine göre %10 anlamlılık seviyesinde normal dağılım göstermeyen toplam 7 ülke bulunurken petrol tüketim değerlerine göre ise toplam 5 ülke normal dağılıma uymamaktadır.

CO2 emisyonu ile petrol tüketim değerleri arasındaki uzun ve kısa dönem ilişki doğrusal olmayan gecikmesi dağıtılmış otoregresif (NARDL) yöntemi kullanılarak incelenmiştir. Shin vd. (2014) tarafından önerilen NARDL yöntemi ait metodolojinin detaylı incelemesi için ilgili makaleye bakılabilir. NARDL yöntemine ait temel denklem ve uzun ve kısa dönem asimetrik ilişkilere ait hipotezler aşağıdaki gibidir.

Hata düzeltme modelinin uygulanmasıyla NARDL yöntemine ait denklem

$$\Delta y_t = \alpha_0 + \sum_{i=1}^{m} \alpha_{1i}\, \Delta y_{t-i} + \sum_{i=0}^{m} (w_i^{+} \Delta x_{t-1}^{+} + w_i^{-} \Delta x_{t-1}^{-}) + \alpha_3 y_{t-1} + \alpha_4 x_{t-1}^{+} + \alpha_5 x_{t-1}^{-} + \varepsilon_t \quad (1)$$

şeklinde olup uzun dönem asimetrik ilişkiye ait hipotezler aşağıdaki gibi kurulur.

$H_0: (-\alpha_4/\alpha_3) = (-\alpha_5/\alpha_3) \rightarrow$ Uzun dönem simetrik ilişki

$H_1: (-\alpha_4/\alpha_3) \neq (-\alpha_5/\alpha_3) \rightarrow$ Uzun dönem asimetrik ilişki

Kısa dönem asimetrik ilişkiye ait hipotezler ise

$H_0: w_i^{+} = w_i^{-} \rightarrow$ Kısa dönem simetrik ilişki

$H_1: w_i^{+} \neq w_i^{-} \rightarrow$ Kısa dönem asimetrik ilişki

şeklinde kurulur (Hepsağ, 2022).

Ampirik Bulgular

Doğrusal olmayan ARDL yaklaşımının uygulanabilmesi için öncelikle ülkelerin durağanlık derecelerinin belirlenmesi gerekmektedir. Durağanlık derecelerinin gösterimi için tümleşme analizi kullanılacaktır. Eğer bir seri düzey seviyesinde durağan olarak bulunursa 0. Dereceden tümleşik olarak ifade edilecektir. Bir başka ifade ile düzey seviyesinde durağan bulunan bir seri I(0) olarak gösterilecektir. Diğer durumda ise seri fark alındığında durağan hale geliyorsa fark alınma değeri serinin tümleşme derecesini ifade edecektir. Birinci farkı alındıktan sonra durağan hale gelen seri için birinci dereceden tümleşik ifadesi kullanılabilir. Başka bir ifade ile birinci farkı alındıktan sonra durağan hale gelen seri için I(1) ifadesi kullanılabilir. ARDL yaklaşımı için öncelikle bağımlı değişkenin I(1) olarak bulunması gereklidir. Bağımsız değişkenler için böyle bir kısıtlama bulunmamaktadır. Bağımsız değişkenler birinci farkı alındıktan sonra ya da düzey değerlerinde durağan olarak denkleme dahil edilebilir. Bu durumda bağımsız değişkenler I(1) veya I(0) olması durumunda denkleme dahil edilebilmektedir. Fakat bağımsız değişkenlerin ikinci farkı alındıktan sonra durağan hale gelmemesi gerekmektedir. Bu nedenle tümleşme derecesi I(2) olan bir değişken ARDL yaklaşımında bağımsız değişken olarak denkleme dahil edilememektedir. ARDL yaklaşımının uygulanabilmesi için öncelikle serilerin durağanlık durumlarının belirlenmesi gerekmektedir. Durağanlık mertebeleri belirlenen değişkenler aşağıdaki tabloda gösterilmiştir.

Tablo 3. Ülkelere ait CO2 emisyon ve petrol tüketim değişkenlerinin durağanlık mertebeleri

Ülkeler	Durağanlık Mertebesi (CO2)	Durağanlık Mertebesi (Petrol tüketimi)
Almanya	I(1)	I(0)
Belçika	I(1)	I(1)
Çek Cum.	I(1)	I(1)
Danimarka	I(1)	I(1)
Fransa	I(1)	I(0)
Hollanda	I(1)	I(1)
İngiltere	I(1)	I(0)
İspanya	I(1)	I(1)
İsveç	I(0)	I(0)
İtalya	I(1)	I(1)
Macaristan	I(0)	I(0)
Polonya	I(1)	I(1)
Romanya	I(1)	I(1)

Not: Serilere geleneksel ADF birim kök testi uygulanmış olup %10 anlamlılık seviyesi dikkate alınmıştır.

Durağanlık test sonuçlarına göre İsveç ve Macaristan'ın bağımlı değişkeni olan karbondioksit emisyon serileri düzey değerinde durağan bulunmuştur. NARDL eşbütünleşme testi sonuçlarına göre bağımlı değişkenlerin birinci farkta durağan olması gerekmektedir. Bu nedenle ilgili ülkeler analizden çıkarılmıştır.

Tablo 4. NARDL eşbütünleşme test sonuçları

Ülkeler	Uzun Dönem Asimetrik İlişki Test İst.	Kısa Dönem Asimetrik İlişki Test İst.	Sınır Testi Test İst.
Almanya	8635***	5587***	6.19**
Belçika	224***	836***	9.72***
Çek Cum.	220***	404***	4.45
Danimarka	1.85	25.21***	17.49***
Fransa	737***	613***	11.42***
Hollanda	411***	146***	3.80
İngiltere	1169***	233***	3.14
İspanya	351***	337***	4.06
İtalya	229***	70***	2.98
Polonya	1196***	3284***	2.97
Romanya	281***	1297***	1.22

Not: ** ve *** sırasıyla %5 ve %1 güven düzeylerinde istatistiksel olarak anlamlılığı ifade etmektedir.

Doğrusal olmayan ARDL test sonuçlarına göre incelenen bütün ülkeler için uzun dönemli ve kısa dönemli asimetrik ilişki tespit edilmiştir. Eşbütünleşme testinin ifade eden sınır testi sonuçlarına göre Almanya, Belçika, Danimarka ve Fransa için eşbütünleşme ilişkisi tespit edilmiştir.

Sonuç

Bu çalışmada en yüksek karbondioksit emisyon ve petrol tüketim değerlerine sahip olan 13 Avrupa ülkesi için doğrusal olmayan ARDL yaklaşımı uygulanmıştır. 1965 ile 2022 arasındaki yıllık veriler kullanılarak elde edilebilen en geniş zaman aralığı incelenmiştir. Karbondioksit emisyonu ile petrol tüketimi arasındaki eşbütünleşme ilişkisi incelenmiştir. Ülkelerin karbondioksit emisyon değerleri ve petrol tüketimleri arasındaki uzun dönemli ilişkinin incelenmesi karbondioksit emisyonunun kaynağının belirlenmesi açısından önem arz etmektedir. Literatürde sıkça kullanılan NARDL yaklaşımı çerçevesinde incelen karbondioksit emisyon ve petrol tüketim arasındaki ilişki sonuçlarına göre ülkeler bazında farklı bulgular elde edilmiştir. NARDL testinin uygulanabilmesi öncelikle değişkenlerin durağanlık mertebelerinin belirlenmesi gereklidir. Bu nedenle

her ülkenin karbondioksit emisyon ve petrol tüketim serileri için birim kök testleri uygulanmıştır. Uygulanan geleneksel ADF birim kök testleri neticesinde NARDL testinin uygulanabileceği ülkeler belirlenmiştir. İsveç ve Macaristan haricinde geri kalan 11 Avrupa ülkesi için NARDL testinin uygulanabileceği tespit edilmiştir. NARDL test sonuçlarına göre analize dahil edilen 11 Avrupa ülkesi için de kısa ve uzun dönemli asimetrik ilişki tespit edilmiştir. Eşbütünleşme testi sonuçlarına göre de Almanya, Belçika, Danimarka ve Fransa'nın karbondioksit emisyonları ve petrol tüketimleri arasında eşbütünleşme ilişkisi tespit edilmiştir.

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SEÇİLİ AVRUPA ÜLKELERİ'NDE KARBONDİOKSİT EMİSYONLARI YAKINSIYOR MU? DOĞRUSAL OLMAYAN BİRİM KÖK TESTLERİNDEN KANITLAR

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ÖZET

Küresel iklim değişikliğinin etkilerini arttırmasıyla birlikte ülkeler son yıllarda karbondioksit gibi sera etkisi yapan gazların salınımını azaltmada ciddi tedbirler almaya başlamıştır. Küresel iklim değişikliğinin etkilerinin ilk konuşulmaya başlandığı Avrupa kıtasında bulunan ülkeler özellikle zehirli gazların atmosfere salınımıyla ilgili sıkı yönetmelikleri devreye sokmaya başlamışlardır. Çalışmamızda da küresel iklim değişikliğinin en yüksek sesle konuşulmaya başlandığı Avrupa ülkeleri incelenmektedir. Enerji üretiminde çevreye salınan karbondioksit gazı emisyon değerlerinin en fazla olduğu 13 Avrupa ülkesi analize dahil edilmiştir. Analize konu olan Avrupa ülkeleri; Almanya, Belçika, Çek Cumhuriyeti, Danimarka, Fransa, Hollanda, İngiltere, İspanya, İsveç, İtalya, Macaristan, Polonya ve Romanya'dır. Veri seti için bulunabilen en geniş zaman aralığı alınarak 1965-2022 yılları arasındaki karbondioksit emisyon değerleri incelenmiştir. İncelenen 13 Avrupa ülkesi için alınan tedbirlerin faydalı olup olmadığını sorgulama amacıyla yakınsama analizi kullanılmıştır. Yakınsama analizi için 13 Avrupa ülkesinin karbondioksit emisyon değerlerinin grup ortalamasına yakınsama durumu birim kök testleriyle incelenmiştir. Analiz için öncelikle kesirli Fourier birim kök testleri kullanılmıştır. Test sonuçları doğrultusunda incelenen Avrupa Ülkeleri'nden hiçbirinin Fourier terimleri anlamlı bulunamamıştır. Fourier terimlerinin istatistiksel olarak anlamsız bulunmasıyla birlikte Fourier tipi olmayan farklı birim kök testleri kullanılmıştır. Yakınsama analizi için ani kırılmaları dikkate alan RALS tipi birim kök testleri kullanılmıştır. RALS tipi birim kök testleri normal dağılmama durumunu dikkate aldığı için daha etkin parametre tahminleri sunması açısından tercih konusu olmuştur. Hem trendde hem de sabit terimde iki kırılmayı yakalayabilen RALS-LM birim kök testinin kullanılması da yakınsamanın tespit edilebilmesi açısından önem arz etmektedir. Yumuşak geçişleri ifade eden Fourier fonksiyonlarının anlamsız çıkması analize dahil edilen ülkeler için yapısal değişimin olmadığı olarak yorumlanmamalıdır. Bu nedenle ani kırılmaları dikkate alan birim kök testleri yumuşak geçişler bulunmasa dahi tercih edilmiştir. RALS birim kök testi sonucunda Fransa, İsveç, Polonya haricinde ele alınan 10 Avrupa ülkesinin karbondioksit salınımlarının yakınsama davranışı gösterdiği tespit edilmiştir.

Anahtar kelimeler: Karbondioksit emisyonu, Yakınsama, RALS-tipi birim kök testi

ABSTRACT

With the increasing effects of global climate change, countries have started to take serious measures to reduce the emission of greenhouse gases such as carbon dioxide in recent years. Countries in the European continent, where the effects of global climate change first started to be discussed, have started to put into effect strict regulations, especially regarding the release of toxic gases into the atmosphere. In our study, European countries, where global climate change has started to be discussed most loudly, are analyzed. The 13 European countries with the highest carbon dioxide gas emission values released to the environment in energy production are included in the analysis. Carbon dioxide emission values between 1965-2022 are analyzed by taking the widest time interval available for the data set. Convergence analysis is used to question whether the measures taken for the 13 European countries are beneficial or not. For the convergence analysis, the convergence of carbon dioxide emission values of 13 European countries to the group average was analyzed by unit root tests. Firstly, fractional Fourier unit root tests were used for the analysis. According to the test results, the Fourier terms of none of the European countries analyzed were found to be significant. As the Fourier terms were found to be statistically insignificant, different non-Fourier type unit root tests were used. For convergence analysis, RALS-type unit root tests that take into account sudden breaks were used. Since RALS-type unit root

tests take into account the non-normal distribution, they are preferred in terms of providing more efficient parameter estimates. The use of the RALS-LM unit root test, which can capture two breaks in both the trend and the constant term, is also important in terms of detecting convergence. The fact that the Fourier functions expressing smooth transitions are insignificant should not be interpreted as the absence of structural change for the countries included in the analysis. For this reason, unit root tests that take into account sudden breaks are preferred even if there are no smooth transitions. As a result of the RALS unit root test, it was found that the carbon dioxide emissions of the 10 European countries except France, Sweden, and Poland showed convergence behavior.

Keywords: Carbon dioxide emission, Convergence, RALS-type unit root test

Giriş

Birleşmiş Milletler İklim Değişikliği Çerçeve Sözleşmesi'nin hedefi, küresel iklim değişikliği ve sera gazı etkisiyle mücadele etmenin bir yolu olarak CO2 emisyonlarını dengelemek ve azaltmaktır. Bu hedefe ise, kişi başına düşen emisyonlarda sürdürülebilirliği sağlayacak belirli bir hedefe yakınsama sağlanmasıyla ulaşmak mümkündür. Gelişmiş ülkelerde kişi başına düşen emisyonlarda yakınsama sağlanırsa, bu durum gelişmekte olan ülkeleri kendi emisyonlarında bir üst sınırı kabul etmeye teşvik edecektir. Bu da küresel iklim sistemine insan kaynaklı tehlikeli müdahalenin önlenmesine yönelik uzun vadeli küresel bir anlaşmaya varılması sürecinde ilerleme kaydedilmesine yardımcı olacaktır (Romero-Ávila, 2008). Dolayısıyla ekonomik büyümeyi sürdürürken CO2 emisyonlarının kontrol altına alınmasının önemine büyük önem verilmektedir (Li ve Lin, 2015). Özellikle son yıllarda bilim insanları, sera gazı emisyonlarının küresel iklim değişikliğine ve sera etkisine önemli katkıda bulunduğunun bilincine varmıştır. Benzer şekilde siyasi ve ekonomik aktörler artık enerji tasarrufu ve atmosfere sera gazı emisyonlarının azaltılması için önlemler almanın öneminin farkına varmaya başlamışlardır (Presno vd., 2018).

Kişi başına düşük emisyona sahip birçok gelişmekte olan ülke, kişi başına yüksek emisyona sahip gelişmiş ülkelerden emisyonlarını azaltmalarını beklediğinden, emisyonların paylaşım planında adalet ve hakkaniyet konusu ciddi şekilde tartışılmaktadır. Ancak, kişi başına düşen emisyonların birbirine yakınsamaması halinde, kişi başına düşen emisyon tahsisi, uluslararası emisyon ticareti ve/veya emisyon yoğun sanayilerin yer değiştirmesi yoluyla büyük kaynak transferlerine yol açacaktır (Apergis ve Payne, 2017).

Emisyon yakınsamasının büyüklüğünün ampirik olarak araştırılması için, son zamanlarda araştırmacılar CO2 emisyonlarındaki şokların kalıcı olup olmadığını değerlendirmek için birim kök testlerine güvenmişlerdir ve literatürde karbondioksit yakınsamasının incelendiği birçok çalışma bulunmaktadır. Bu çalışmada ise kişi başı karbondioksit emisyon yakınsaması CO2 emisyon değerlerinin en yüksek olduğu 13 Avrupa ülkesi için RALS-LM birim kök testi kullanılarak incelenmiştir. CO2 emisyon yakınsamasını konu edinen çalışmalardan bazıları aşağıda özetlenmiştir.

Robert vd. (2010), Avrupa Birliği'ne üye 22 ülke için kişi başı CO2 emisyon yakınsamasını 1971-2006 dönemleri arasında Bayesian shrinkage tahmin yöntemi kullanarak analiz etmişler ve mutlak yakınsama olduğunu göstermişlerdir.

Acaravcı ve Erdoğan (2016), 1960-2011 dönemi için 7 bölge için kişi başı CO2 yakınsamasını ikinci nesil panel veri yöntemleriyle analiz etmişlerdir. Yapısal kırılmalar altında 7 bölge içinde CO2 emisyon yakınsamasının geçerli olduğunu göstermişlerdir.

Behboudi vd. (2017), MENA ülkeleri için mekânsal dinamik panel yöntemlerini kullanarak 1970-2010 yılları için CO2 emisyon yakınsamasını incelemişlerdir ve zayıf mutlak yakınsamaya dair bulgulara ulaşmışlardır.

Tiwari ve Mishra (2017), 18 Asya ülkesinde CO2 emisyon yakınsamasını incelemek için parametrik testler için beta ve sigma yakınsamasını parametrik olmayan testler için ise Kernel yoğunluk tahminlerini kullanarak yakınsamayı göstermişlerdir.

Rios ve Gianmoena (2018), 1970-2014 dönemlerinde 141 ülke için kişi başı CO2 emisyon yakınsamasını dinamik mekânsal panel ekonometrik yöntemlerle incelemişler ve incelenen ülkeler arasında yakınsama olduğunu göstermişlerdir.

Kounetas (2018), 1970-2010 dönemleri arasında AB-23 ülkeleri için enerji tüketimi ve CO2 emisyon yakınsamalarını regresyon ve dinamik dağılım yaklaşımları ile inceleyerek bütün değişkenler için AB örnekleminde yakınsamanın geçerli olmadığını göstermiştir.

Churchill vd. (2020), gelişmekte olan 17 ekonomi için kişi başı CO2 emisyonunun stokastik yakınsamasını 1921-2014 dönemleri için LM ve RALS-LM birim kök testleri ile analiz etmişlerdir. Analize dahil edilen 17 ülkeden 11'inde stokastik yakınsama olduğunu göstermişlerdir.

Ye vd. (2020), G7 ülkeleri ve Çin için kişi başı CO2 emisyon yakınsamasını 1950-2013 dönemlerinde geleneksel ve Fourier kantil birim kök testleri ile incelemişlerdir. Geleneksel birim kök testlerinin sonuçlarından incelenen hiçbir ülkede yakınsama bulunamazken Fourier kantil birim kök testinde ise sadece Almanya, İtalya ve Birleşik Krallık için yakınsamanın varlığını göstermişlerdir.

Yıldız ve Boz (2020), MENA ülkelerinde CO2 yakınsamasını 1965-2014 yılları arasında CADF birim kök testini kullanarak incelemişlerdir. Analiz sonuçlarından incelenen ülkelerde yakınsama olduğu bulgusuna rastlanmıştır.

Nazlıoğlu vd. (2021), çapraz korelasyonları ve yapısal kırılmaları hesaba katan yeni bir panel durağanlık testi önererek 13 OPEC üyesi ve 18 OPEC üyesi olmayan petrol üretici ülkelerdeki CO2 emisyon yakınsamasını 1960-2016 yılları arasında incelemişlerdir. Literatürde yapılan diğer çalışmalara kıyasla zayıf stokastik yakınsamaya dair kanıtlar bulmuşlardır.

Cialani ve Mortazavi (2021), AB-28 ülkelerindeki sektörel bazlı kişi başı CO2 emisyon yakınsamasını log-t testini (kulüp yakınsaması)1970-2018 dönemleri için incelemişler ve incelenen sektörlere göre kulüp yakınsamasının varlığına dair karma sonuçlar elde etmişlerdir.

Yazıcı ve Çil (2021), Fourier eşbütünleşme testi kullanarak Avrupa ülkeleri arasında kişi başı CO2 emisyon yakınsamasını 1965-2019 dönemleri için incelemişlerdir. Analize dahil edilen ülkelerin yaklaşık %40'ı ile Avrupa ortalaması arasında eşbütünleşme ilişkisi olduğu gösterilerek söz konusu ülkeler ile Avrupa ortalaması için CO2 yakınsamasının geçerli olduğu belirtilmiştir.

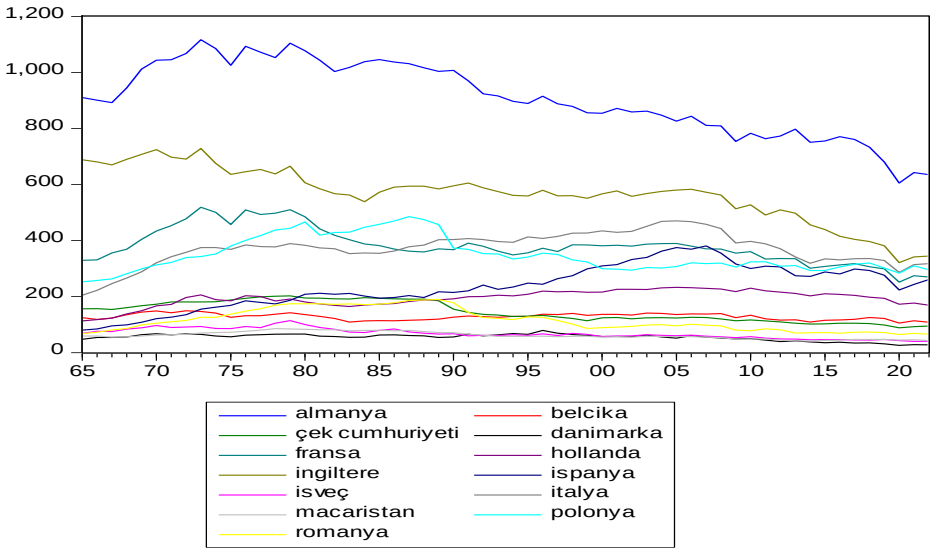
Kardaşlar (2022), karbon emisyonu en yüksek 20 ülke için 1965-2020 dönemlerinde kişi başı CO2 emisyon yakınsamasını Fourier panel durağanlık testi kullanarak incelemiş ve hem panelin geneli için hem de incelenen 20 ülkeden 16'sında yakınsama olduğunu göstermiştir.

Zheng ve Yuan (2023), 1997-2018 dönemleri için Çin'in 30 şehrinde altı büyük sektördeki kişi başı CO2 yakınsamasını beta ve kulüp yakınsama testlerini kullanarak analiz etmişler ve altı ana sektörün tamamının mutlak ve koşullu beta yakınsaması gösterdiğini ve kulüp yakınsamasını destekleyici bulgular elde etmişlerdir.

Lee vd. (2023), 1960-2018 yılları arasında 30 OECD ülkesi için kişi başına düşen karbondioksit emisyonlarının stokastik yakınsamasını Payne vd. (2022) tarafından geliştirilen ve faktör yapısında iki yapısal kırılmaya ve çapraz korelasyona izin veren bir testini kullanarak kişi başına CO2 emisyonlarının yakınsamadığını göstermişlerdir.

Veri ve Yöntem

Karbondioksit emisyon verileri British Petrol (BP)'ün yayınladığı enerji raporlarından alınmıştır. Ülkelere ait karbondioksit emisyon değerleri milyon ton cinsinden ifade edilmektedir. 1965-2022 yılları arasını kapsayan veri seti için her bir ülkeye ait toplam 58 adet gözlem bulunmaktadır. Karbondioksit gazı emisyon yakınsaması için en yüksek emisyon değerine sahip 13 Avrupa ülkesi incelemeye alınmıştır. Veri seti için kullanılan karbondioksit emisyon değerleri fosil yakıt tüketiminden kaynaklanan karbondioksit emisyon değerlerini göstermektedir. Karbondioksit emisyon değerlerinin analizine geçilmeden önce grafiksel gösterimler incelenecektir. Grafiksel gösterimden de anlaşılacağı üzere en yüksek karbondioksit gazı emisyon değerine sahip ülke mavi renkle gösterilen Almanya olarak gözlemlenmektedir. Avrupa'nın en büyük ülkelerinden biri olan ve sanayi üretim kapasitesiyle öne çıkan Almanya'nın karbondioksit emisyon değerinin en yüksek olması beklenen bir durum olarak ifade edilebilir. İkinci en yüksek değere sahip olarak bulunan İngiltere ise yeşil rengiyle öne çıkmıştır. İngiltere'yi takip eden Fransa ise karbondioksit salınımında üçüncü sırayı almaktadır. Fransa'yı gri renkle takip eden İtalya ve turkuaz ile renklendirilmiş Polonya takip etmektedir.



Grafik 1. Ülkelere ait karbondioksit emisyon değerleri

Genel hatlarıyla ülkelerin karbondioksit emisyon değerleri incelendiğinde zaman boyunca azalma eğiliminin varlığı gözlemlenmektedir. Veri setinin başlangıç yılı olan 1965 yılından günümüze doğru karbondioksit emisyon değerlerinin seçilmiş Avrupa ülkeleri için yakınsama gösterdiği grafiksel gösterimden de anlaşılabilmektedir.

Tablo 1. Değişkenlere ait tanımlayıcı istatistikler

Ülkeler	Gözlem Sayısı	Ort.	Medyan	Standart Sapma	Çarpıklık	Basıklık	Jarque-Bera(JB)	JB Olasılık
Almanya	58	907.16	898.98	132.50	-0.31	2.18	2.56	0.28
Belçika	58	128.20	129.16	11.29	-0.11	2.04	2.36	0.31
Çek Cumhuriyeti	58	146.29	133.48	36.16	0.18	1.54	5.48	0.06
Danimarka	58	54.95	57.46	11.90	-0.85	3.03	7.06	0.03
Fransa	58	381.40	371.52	62.64	0.49	2.92	2.31	0.32
Hollanda	58	194.06	199.86	28.47	-0.95	3.71	9.94	0.01
İngiltere	58	567.32	575.18	96.55	-0.71	3.25	5.05	0.08
İspanya	58	235.46	230.08	77.27	-0.11	2.35	1.14	0.56
İsveç	58	68.34	64.75	17.80	0.45	2.47	2.66	0.26
İtalya	58	371.64	377.66	57.67	-0.70	3.62	5.72	0.06
Macaristan	58	61.36	58.24	12.72	0.31	1.99	3.37	0.19
Polonya	58	347.82	323.80	61.97	0.79	2.46	6.78	0.03
Romanya	58	115.24	101.52	40.03	0.52	1.88	5.62	0.06

Seçilmiş Avrupa ülkelerinin karbondioksit emisyonlarına ait tanımlayıcı istatistikler yukarıdaki tabloda gösterilmiştir. Ülkelere ait tanımlayıcı istatistikler genel olarak incelendiğinde en yüksek karbondioksit emisyon ortalamasına sahip ülke yaklaşık 907 milyon ton ile Almanya olarak gözlemlenmektedir. Ortalamanın en düşük olduğu ülkenin ise Danimarka olduğu tespit edilmiştir. Maksimum gözlem değerine sahip olan ülke yine Almanya olarak gözlenirken minimum gözlem değerine sahip olan ülke ise Danimarka olarak bulunmuştur. Normal dağılım incelendiğinde ise %5 anlamlılık seviyesinde Danimarka, Hollanda ve Polonya hariç diğer ülkelerin karbondioksit emisyon değerlerinin normal dağılmadığı tespit edilmiştir. Analizde kullanılan Meng vd. (2017) tarafından önerilen RALS-LM birim kök testine ait metodoloji aşağıdaki gibi verilmiştir.

Meng vd. (2014) tarafından önerilen RALS-LM testi mevcut yapısal kırılmalar hesaba katılmadığında güç kaybettiği için Meng vd. (2017) trend değişimlerine izin vererek bu testi genişletmişlerdir ve çoklu trend

kırılmalarına ve normal olmayan hatalara izin veren yeni bir kalıntıları genişletilmiş en küçük kareler-Lagrange çarpanı (RALS-LM) birim kök testini önermişlerdir (Meng, 2017).

İlk olarak LM test regresyonuna ait gösterim aşağıdaki gibidir:

$$y_t = \delta' Z_t + e_t, \qquad e_t = \beta e_{t-1} + \varepsilon_t \tag{1}$$

$$\Delta y_t = \delta' \Delta Z_t + \phi \tilde{S}_{t-1} + e_t \tag{2}$$

şeklinde olup burada Burada $Z_t = [1, t]'$ bir trend fonksiyonu ile olağan birim kök testinde kullanılır. Birim kök boş hipotezi $\beta = 1$'dir. Lee ve Strazicich (2003)'teki C modeline benzer şekilde, hem seviye kaymasına hem de trend kaymasına izin veren daha genel bir model $Z_t = [1, t, D_{1t}, \dots, D_{Rt}, DT_{1t}, \dots, DT_{Rt}]'$ şeklinde tanımlanabilir ve burada D_{it} ve DT_{it} sırasıyla inci seviye ve trend kırılmalarının konumlarını gösteren kukla değişkenlerdir. Ayrıca R ise yapısal kırılmaların maksimum sayısını göstermektedir.

LM prensibine dayanan birim kök test istatistiği aşağıdaki regresyondan elde edilmektedir.

Burada $\tilde{S}_t$, $\tilde{S}_t = y_t - \tilde{\psi} - \tilde{\delta}' Z_t$ kullanılarak hesaplanan LM trendden arındırılmış y_t serisidir. Burada δ', y_t ve Z_t'nin birinci farkının kullanıldığı Δy_t'nin ΔZ_t üzerine regresyonunda elde edilen katsayı vektörüdür.

RALS prosedüründen elde edilen $\widehat{w}_t$ terimi aşağıdaki gibi olup,

$$\widehat{w}_t = h(\hat{e}_t) - \widehat{K} - \hat{e}_t \widehat{D}_2 \tag{3}$$

Burada $h(\hat{e}_t) = [\hat{e}_t^2, \hat{e}_t^3]'$, $\widehat{K} = \frac{1}{T}\sum_{t=1}^{T} h(\hat{e}_t)$ ve $\widehat{D}_2 = \frac{1}{T}\sum_{t=1}^{T} h'(\hat{e}_t)$ şeklindedir. $m_j = T^{-1}\sum_{t=1}^{T} \hat{e}_t^j$ eşitliği kullanılarak $\widehat{w}_t$ ifadesi aşağıdaki gibi düzenlenir.

$$\widehat{w}_t = [\hat{e}_t^2 - m_2, \hat{e}_t^3 - m_3 - 3m_2\hat{e}_t]' \tag{4}$$

(2) eşitliği ile verilen denkleme (4) eşitliği eklenerek RALS-LM testi aşağıdaki gibi elde edilir.

$$\Delta y_t = \delta' \Delta Z_t + \phi \tilde{S}_{t-1}^* + \gamma' \widehat{w}_t + u_t \tag{5}$$

Test istatistiği ise $\tau_{RALS-LM} \rightarrow \rho\tau_{LM} + \sqrt{1-\rho^2}N(0,1)$ şeklinde olup Meng vd. (2014)'de önerilen test istatistiği ile aynı olup ρ^2 katsayısına bağlı olarak RALS-LM testinin kritik değerleri Meng vd. (2014) ve Meng vd. (2017) tarafından sunulmuştur. Ayrıca ρ^2, $\hat{\rho}^2 = \hat{\sigma}_u^2 / \hat{\sigma}_e^2$ olarak tahmin edilen ve RALS-LM denkleminin hata teriminin varyansının tahmininin geleneksel LM denkleminin hata varyansının tahminine oranı biçimde elde edilen bir parametredir (Hepsağ, 2022).

Bulgular

Karbondioksit yakınsamasının analizinin yapılabilmesi için birim kök testleri kullanılacaktır. Öncelikle Omay (2015)'in literatüre kazandırdığı kesirli Fourier birim kök testi yakınsamanın tespiti için uygulanmış olup sonuçlar aşağıdaki tabloda verilmiştir.

Tablo 2. Omay (2015) Kesirli Fourier Birim Kök Test Sonuçları

Ülkeler	Kesirli Frekans Değeri k^{fr}	F İstatistik Değeri F(k^{fr})	Test İstatistiği $\tau_{DF_c}^{fr}$	Optimal Gecikme	Minimum Kalıntı Kareler Toplamı
Almanya	0.10	0.89	-2.98	1	0.59
Belçika	0.20	1.95	-2.98	0	0.03
Çek Cum.	0.20	1.39	-1.57	0	0.02
Danimarka	0.20	5.16	-4.12	0	0.01
Fransa	0.20	1.87	-2.47	1	0.25
Hollanda	0.20	5.72	-2.86	1	0.04
İngiltere	0.20	5.87	-3.55	1	0.31
İspanya	0.20	2.33	-2.17	0	0.16
İsveç	0.20	0.20	-3.08	0	0.02
İtalya	0.10	2.60	-2.17	0	0.04
Macaristan	0.10	2.44	-2.29	0	0.00
Polonya	0.10	1.90	-2.28	0	0.22
Romanya	0.10	2.60	-2.17	0	0.04

Omay (2015) Kesirli Fourier birim kök testinin sonuçları incelendiğinde ilk olarak Fourier terimlerinin anlamlılığını sınayan F istatistiklerinin incelenmesi gereklidir. Eğer Fourier terimlerinin anlamlı olmadığını ifade eden temel F testi hipotezi reddedilirse Omay (2015) testinde ifade edilen $\tau_{DF_c}^{fr}$ test istatistiği sınanır. Fakat ilgili tabloda görüldüğü üzere hiçbir ülke için kesirli Fourier terimlerinin anlamlı olmadığını ifade eden temel hipotez reddedilememiştir. Bu nedenle kesirli Fourier birim kök testi uygulanan hiçbir ülkenin Fourier terimleri istatistiksel olarak anlamlı bulunamamıştır. Fourier terimleri anlamlı olmadığı için test denklemi standart birim kök test denklemlerine evrilmektedir. Bu nedenle uygulanan kesirli Fourier birim kök testinden daha farklı bir birim kök testi uygulanmalıdır.

Tablo 3. Meng vd. (2017) RALS-LM Birim Kök Testi Sonuçları

Ülkeler	1.Kırılma Tarihi	2.KırılmaTarihi	Test İstatistiği $\tau_{RALS-LM}$	Hesaplanan ρ^2 değeri	Optimal Gecikme Uzunluğu
Almanya	1978:01	1999:01	-5.11***	0.90	5
Belçika	1983:01	2003:01	-4.76**	0.60	3
Çek Cum.	1988:01	2004:01	-7.33***	0.90	9
Danimarka	1989:01	1998:01	-5.15***	0.90	3
Fransa	1976:01	2016:01	-3.06	0.90	1
Hollanda	1979:01	2009:01	-4.81**	1	4
İngiltere	1980:01	2006:01	-5.56***	0.90	6
İspanya	1991:01	2006:01	-6.54***	0.90	7
İsveç	1978:01	1983:01	-2.83	1	0
İtalya	1988:01	1992:01	-4.26*	1	1
Macaristan	1989:01	2014:01	-7.44***	0.90	9
Polonya	1987:01	1992:01	-3.51	0.90	0
Romanya	1988:01	1992:01	-4.26*	1	1

Not: *, **, *** işaretleri sırasıyla serinin %10, %5 ve %1 anlamlılık düzeylerinde birim köklü olduğunu gösteren temel hipotezin reddedildiğini ifade etmektedir.

Yukarıdaki tabloda seriler için Meng vd. (2017) RALS-LM birim kök testi uygulanmıştır. Sabitte ve kırılmada toplam 2 kırılmayı tespit edebilen RALS-LM birim kök testi tercih edilmiştir. Hata terimlerinde normal dağılmamayı dikkate alan bir test olması ve iki farklı yapısal kırılmayı tespit edebildiği için yakınsama analizinde RALS-LM birim kök testi tercih edilmiştir. Analiz sonuçlarına göre Almanya, Belçika, Çek Cumhuriyeti, Danimarka, Hollanda, İngiltere, İspanya, İtalya, Macaristan ve Romanya'nın grup ortalamalarına doğru yakınsama davranışı gösterdikleri tespit edilmiştir.

Sonuç

Küresel iklim değişikliğinin gün geçtikçe ciddi sonuçlar doğurmasıyla birlikte ülkeler, birlikler, iş birliği örgütleri gibi uluslararası organizasyonlar iklim krizinin önlenmesi için çeşitli tedbirler almaya başlamışlardır. Bu çalışmada 13 Avrupa ülkesinin enerji üretimi için yaptığı karbondioksit emisyon değerleri incelenmiştir. En yüksek karbondioksit emisyon değerlerine sahip olan 13 Avrupa ülkesinin 1965-2022 yılları arasındaki karbondioksit emisyonları ele alınmıştır. Avrupa'da yer alan ve kıta içinde en büyük ekonomilere sahip olan ülkelerin karbondioksit emisyonlarının grup ortalamasına yakınsama davranışları güncel birim kök testleriyle incelenmiştir.

Önce Fourier tabanlı birim kök testlerinden Omay (2015) kesirli Fourier birim kök testi uygulanmıştır. Fakat serilere ait Fourier terimlerinin hiçbiri anlamlı bulunamamıştır. Bu nedenle Fourier birim kök testlerinden daha farklı nitelikte olan güncel birim kök testlerinden RALS-LM birim kök testi uygulanmıştır. RALS birim kök analizleri seriye ait birim kök test regresyonlarından elde edilen kalıntıların normal dağılmamasını dikkate almaktadır. Bu nedenle kalıntıların normal dağılmama durumunda bile güçlü sonuçlar vermektedir.

Fourier terimleri anlamlı bulunamamış olsa bile yapısal kırılmaları dikkate alan RALS-LM birim kök testi kullanılmıştır. Veri setinin 1965 ile 2022 yılları gibi geniş bir aralığı kapsaması nedeniyle yapısal kırılmaların dikkate alınmadığı birim kök testleri serinin durağan olduğunu ifade eden hipotezi reddetme eğiliminde olacaklardır. Bu sebeple yakınsamanın varlığının araştırılabilmesi için yapısal kırılmaları dikkate alan birim kök testi uygulanmıştır. Sonuç olarak ele alınan toplam 13 Avrupa ülkesinde Almanya, Belçika, Çek Cumhuriyeti, Danimarka, Hollanda, İngiltere, İspanya, İtalya, Macaristan ve Romanya'nın grup ortalamalarına doğru yakınsama davranışı gösterdikleri tespit edilmiştir.

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THE RELATIONSHIP BETWEEN RENEWABLE ENERGY AND EMPLOYMENT: THE CASE OF TURKEY

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ABSTRACT

Energy, which penetrates almost all of our lives, is one of the indispensable basic factors determining the level of economic development of countries; our need for energy has increased in parallel with population growth, urbanisation, technological development, globalisation and industrialisation. Today, the fact that 80-90% of the world's energy supply is met from fossil fuels has led to the need to meet the increasing energy demand in harmony with low cost and sustainable environmental purposes. At this point, renewable energy sources come to mind as a solution. The fact that renewable energy resources can renew themselves with a continuous movement, are distributed more fairly, are easy to obtain, support sustainable development and create new employment areas, and have very little damage to the ecosystem compared to fossil fuels makes these resources attractive. In the age we live in, many countries have started to produce and consume renewable energy resources in order to ensure energy supply security by reducing external dependence on energy and to access cleaner energy resources. In addition, the transition to renewable energy sources creates a series of job opportunities for individuals with different qualifications and qualifications. In this context, in this study, the relationship between employment and renewable energy is analysed using the ARDL Border Test Method with the help of the data set for the period 2000-2021 for Turkey. As a result of the analysis, it is found that there is a cointegration relationship between renewable energy and employment in the long run, that is, the series move together in the long run. In this framework, it is thought that with the increase in investments and demand for renewable energy resources in Turkey in the coming years, this situation will be more effective on employment.

Keywords: Renewable Energy, Employment, ARDL Bound Test Approach.

YENİLENEBİLİR ENERJİ VE İSTİHDAM İLİŞKİSİ: TÜRKİYE ÖRNEĞİ

ÖZET

Hayatımızın neredeyse tamamına nüfus eden enerji ülkelerin ekonomik kalkınmışlık düzeyini belirleyen vazgeçilmez temel faktörlerden biri olup; enerjiye olan ihtiyacımız nüfus artışı, kentleşme, teknolojik gelişme, küreselleşme ve sanayileşmeye paralel olarak artmıştır. Günümüzde dünya enerji arzının %80-90'ının fosil yakıtlardan karşılanması artan enerji talebinin düşük maliyetli ve sürdürülebilir çevre amacıyla uyum içerisinde karşılanma ihtiyacını doğurmuştur. Bu noktada çözüm olarak akla yenilenebilir enerji kaynakları gelmektedir. Yenilenebilir enerji kaynaklarının kendini sürekli bir devinimle tazeleyebilmeleri, daha adil bir şekilde dağılmaları, elde edilebilirliğinin kolay olması, sürdürülebilir kalkınmayı desteklemesi ve yeni istihdam alanları yaratması ve ekosisteme verdiği zararın fosil yakıtlarla kıyaslandığında çok az olması bu kaynakları cazip hale getirmektedir. Yaşadığımız çağda birçok ülke enerjide dışa bağımlılığı azaltarak enerji arz güvenliğini sağlamak hem de daha temiz enerji kaynaklarına erişmek üzere yenilenebilir enerji kaynaklarını üretmeye ve tüketmeye başlamıştır. Ayrıca yenilenebilir enerji kaynaklarına geçiş farklı vasıfta ve nitelikte bireyler için bir dizi iş imkanı ortaya çıkarmaktadır. Bu kapsamda çalışmada istihdam ve yenilenebilir enerji arasındaki ilişki Türkiye için 2000-2021 dönemi veri seti yardımıyla ARDL Sınır Testi Yöntemi kullanılarak analiz edilmektedir. Analiz sonucunda uzun dönemde yenilenebilir enerji ile istihdam arasında eşbütünleşme ilişkisi olduğu yani serilerin uzun dönemde birlikte hareket ettiğine ulaşılmıştır. Bu çerçevede, Türkiye'de gelecek yıllarda yenilenebilir enerji kaynaklarına olan yatırımların ve talebin artması ile birlikte bu durumun istihdam üzerinde daha etkili olacağı düşünülmektedir.

Anahtar Kelimeler: Yenilenebilir Enerji, İstihdam, ARDL Sınır Testi Yaklaşımı.

Introduction

Energy is an indispensable concept whose roots date back to the late 18th century and has now penetrated every aspect of life. Factors such as rapid population growth, industrialisation, technological developments, urbanisation, increased production and consumption, migration in countries that have become more interdependent with the effect of globalisation have made energy a key element in both social and economic terms. While realising economic production and consumption activities, energy has been the main input component and at this point it has been one of the main determining factors of economic growth. However, the fact that 80-90 per cent of this main input source is met from fossil fuels in the century we live in has negative effects especially on the environment and foreign trade deficit. The use of fossil fuels causes significant environmental and health problems on a global scale such as CO2 gas emissions, global warming, climate change and shifts. In order to overcome these problems in countries, they have sought more sustainable resources. In order to integrate into this understanding, the orientation towards renewable energy sources has started and continues rapidly. Thus, especially in countries that are dependent on foreign energy, both energy supply security is ensured and measures are taken against the risk of depletion of fossil resources. These resources also contribute to the increase in income and employment while protecting the environment.

The power/force resulting from the release of resources in different forms above and below the ground by means of heat, movement, interaction and vibration is called energy. In physical science terminology, energy is defined as the capacity to do work, such as lifting, accelerating or heating a substance, while in economic terminology, energy includes all energy commodities and energy sources, commodities or resources that contain significant amounts of physical energy and thus offer the ability to do work (Sweeney, 2000). Energy resources are basically classified as non-renewable and renewable. Almost the whole world met its energy needs intensively until the 1990s, and the dependence on energy needs increased with the changes experienced at the micro and macro level. Increasing energy prices after the oil crisis revealed the necessity of diversification of resources. The negative impact of increasing energy prices on the economies of countries after the crisis has revealed the necessity of minimising external dependence and realising resource diversification with domestic means while formulating energy policies (Koçaslan, 2006). As of the current era, the aim of energy policies is to ensure energy supply security, sustainability, reduction of environmental damage and obtaining energy at the least possible cost and uninterruptedly. For this reason, there is a fierce competition on a global scale to have access to and control over energy resources.

Figure 1 below shows the total final energy consumption data by source in the world. According to the current data of the International Energy Agency (IEA), oil ranks first with 38% in 2020, followed by 20% electricity, 16% natural gas, 11% biofuels and wastes, 9.5% coal, 3.5% heat and 1.8% wind, solar, geothermal energy (IEA, 2023). Accordingly, it is clearly seen that non-renewable resources have a higher share in energy consumption in the world than renewable resources.

The continuous increase in population and economic growth means more production and consequently more energy needs. While meeting the need for energy, which is an indispensable input of production, it has become imperative to turn to clean and sustainable resources in a way that minimises damage to the environment. The best alternative to reduce dependence on fossil resources is renewable energy sources. The most important advantages of renewable energy resources are that they can renew themselves with a continuous movement, they are distributed more fairly, they are easy to obtain, they are reliable and the damage to the ecosystem is very small compared to fossil fuels.

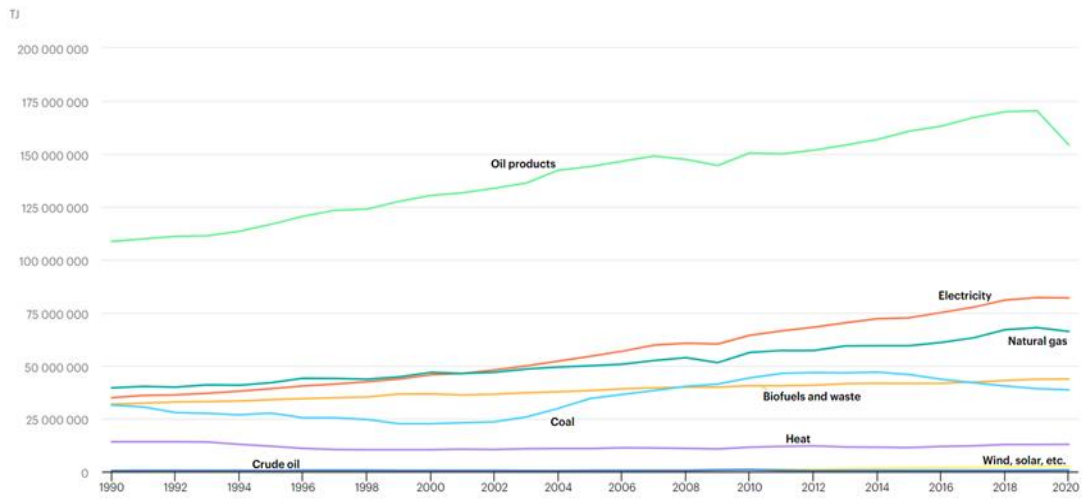

Figure 1. Total Final Energy Consumption by Source

Source: IEA, 2023.

Renewable Energy and Employment

In addition to factors such as energy supply security, environmental impacts and cost, which are among the primary objectives of energy policies, direct employment and export opportunities created by developments in the energy sector also come to the fore. In recent years, as renewable energy has started to be preferred over fossil-based industries in countries around the world, the renewable energy industry currently employs 12.7 million people worldwide and this number is increasing every year. Employment rates in the renewable energy sector are shown in Figure 2. IRENA (International Renewable Energy Agency) has been publishing employment data in the global renewable energy sector since 2012 in the report 'Renewable Energy and Employment'. According to this report, employment in the global renewable energy sector, which was 12 million in 2020, reached 12.7 million in 2021. Nearly two-thirds of this figure is realised in Asia. China alone accounts for 42 per cent of the global total, while the European Union and Brazil account for 10 per cent each, and the USA and India each account for 7 per cent. According to IRENA data, solar photovoltaic energy is by far the technology with the highest employment rate of 33% in the distribution of employment in global renewable energy technology (IRENA, 2022).

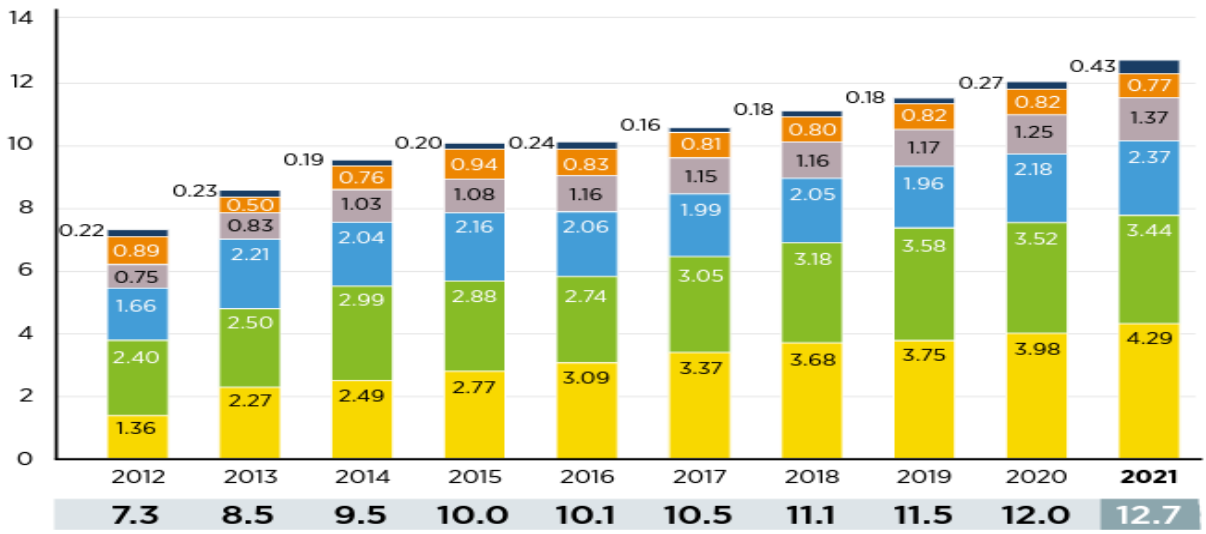

Figure 2. Employment in the Renewable Energy Sector

Source: IRENA, 2022.

It is possible to analyse the types of employment associated with renewable energy sources in 3 different classes: direct employment, indirect employment and induced employment (Meyer and Sommer, 2014; Wei et al., 2010). Employment generated by the energy sector itself at all stages of the life cycle of renewable energy technologies such as R&D studies, production, installation, operation and maintenance of renewable energy technologies refers to direct employment; employment arising in sectors that provide inputs, intermediate goods and services to the renewable energy sector refers to indirect employment. Stimulated employment, on the other hand, includes the job opportunities that arise in other sectors with the spillover effect in parallel with the developments in the renewable energy sector, although they do not have a direct organic link with the sector.

Although the problem of insufficient employment for a sustainable economic order is not a new problem in national economies, high unemployment rates, which is one of the problems that emerged after the global financial crisis in 2007, has directed attention to unemployment, which is a fundamental macroeconomic problem today, although years have passed. This is because unemployment rates hover above the natural rate not only in developing countries but also in some developed countries. However, unemployment rates that remain above the natural rate for a long time bring along social disorders in the long run. In this context, the renewable energy sector should be supported in order to prevent the rapid decline in human capital (Ağpak and Özçiçek, 2018).

Renewable energy investments, which are labour intensive, are considered to be the driving force of employment. In this respect, apart from the integrated employment effect created by renewable energy investments with other known sectors, there is also a need for employment specific to the renewable energy sector. As a matter of fact, at the beginning of this requirement, there are appropriate work teams and qualified labour force to provide consultancy services for renewable energy investment projects. There is also a need for individuals specialised in the field of law in order to implement these projects in accordance with the laws in the country. It is known that the renewable energy sector consists of different sources and these sources are based on different technologies. It develops a number of business lines for the design, production, installation, maintenance and management of these technologies. In addition, the continuous development and adoption of renewable energy technologies contributes positively to the increase in jobs in this sector.

Literature Review

There are relatively limited studies in the literature on the effects of renewable energy investments on employment. The majority of the studies are not analytical, but rather theoretical. In this section of the study, the literature review on the related subject is summarised.

Lehr et al. (2008) analysed the relationship between the renewable energy sector and employment by conducting a comprehensive survey of 1000 people in Germany. According to the findings, if Germany maintains its position in the field of renewable energy, it has the potential to create over 400,000 jobs by 2030.

Apergis and Payne (2010) investigated the relationship between renewable energy consumption and economic growth in a study covering the period 1985-2005 in 20 OECD countries. Employment was used as a control variable in the model and the effect of renewable energy on growth was investigated. Granger causality test was applied with the multivariate error correction model and it was found that there was no causality relationship between employment and renewable energy consumption.

In their study for China, Zhao and Luo (2017) analysed the effects of employment on renewable energy through ARDL Bound Test with the data set for the period 1978-2013. According to the findings, employment has a positive and significant long-run relationship with renewable energy in the specified period for China.

Ağpak and Özçiçek (2018) focused on renewable energy, which is considered as an employment policy instrument. In the study, a panel data analysis covering 59 countries and the period 1991-2014 was conducted to determine the net employment effect of renewable energy use. According to the results obtained, there is a negative relationship between renewable energy use and employment. However, it is determined that youth employment is more negatively affected by the transition to renewable energy use than general employment.

Özsoy and Özpolat (2020) examined the causality relationship between renewable energy, non-renewable energy and employment in high-income developing BRICS and MIST countries for the period 1991-2014 through Bootstrapt Granger Causality Analysis. According to the results of the analysis, a bidirectional

causality relationship was found between renewable energy and employment in Russia, India and Indonesia, while a causality from renewable energy to employment was found in South Africa and Turkey. In China, South Korea and Mexico, no causality relationship was found between renewable energy and employment.

Ordu and Songur (2023) empirically analysed the relationship between renewable energy consumption and employment in Turkey. The existence of this relationship is analysed with the help of ARDL bounds test approach using annual employment, renewable energy consumption, primary energy consumption and capital output coefficient data set for the period 1980-2019. It was found that there is a cointegration relationship between renewable energy consumption and employment in the long run, that is, the series move together in the long run.

Model, Data Set and Methodology

The study aims to empirically analyse the relationship between renewable energy and employment with the help of Turkey's annual data for the period 2000-2021. The motivation of this study for Turkey is the fact that there are few studies on the subject we are dealing with in Turkey in the context of the selected topic. In this context, it is thought that the study will contribute to fill this gap in the literature. Renewable energy data, which is the focal point of the study, is obtained from the renewable energy power capacity and electricity generation figures of the International Renewable Energy Agency-IRENA. The reason for the inclusion of the gross fixed capital formation coefficient in the study is that, based on a production function, the two basic variables for production are labour and capital. In this context, it is important not to exclude employment and its complementary capital variable in the model. Data on employment and gross fixed capital formation variables are taken from the World Bank database. Since IRENA's data were published as of 2000, the starting year was chosen as 2000 and 2021 was chosen as the end year, again depending on the availability of data. The model estimated to empirically test the impact of renewable energy on employment is shown in Equation (1).

(1)

In this equation, *EMP* stands for employment, *LRE* stands for renewable energy and *FC* stands for gross fixed capital formation. In this model, the long-run relationship between variables is analysed using the ARDL bounds test developed by Peseran, Shin and Smith (2001). The ARDL approach is based on the least squares method and unlike classical cointegration analyses, ARDL analysis does not require a unit root test beforehand. This is because there is no need to classify variables as I(1) and I(0) (Sharifi-Renani, 2008). The main advantage of the ARDL model is that cointegration tests can be performed and significant results can be obtained whether the variables are I(1) or I(0) (Pesaran and Pesaran, 1997). However, the ARDL model cannot be applied when the variables are integrated at the 2nd order or higher (Çağlayan, 2006). Another important advantage is that it can be applied to small samples (Kamaruddin and Jusoff, 2009). The ARDL form of the model is shown in equation (2).

$$\Delta EMP_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} \Delta EMP_{t-i} + \sum_{i=1}^{k} \alpha_{2i} \Delta LRE_{1t-i} + \sum_{i=1}^{k} \alpha_{3i} \Delta FC_{2t-i} + \omega_1 EMP_{t-1} + \omega_2 LRE_{t-1} + \omega_3 FC_{t-1} + \mu_t \quad (2)$$

In equation (2), Δ denotes the first order difference of the series, α_0 denotes the slope coefficient, α_1, α_2 and α_3 denote the short-run relationship between the variables, and ω_1, ω_2 and ω_3 coefficients denote the long-run relationship between the variables. In addition, the lag length of the variables in the ARDL model was determined with the help of Akaike Information Criterion. On the other hand, the hypotheses tested for validity in the study are;

$H_0 = \omega_1 = \omega_2 = \omega_3 = 0$ → There is no cointegration.

$H_1 \neq \omega_1 \neq \omega_2 \neq \omega_3 \neq 0$ → There is cointegration.

In this context, in order to test the validity of the hypotheses in the ARDL bounds test, i.e. to decide whether there is a cointegration relationship between the variables, the critical values derived asymptotically by Peseran et al. (2001) are used. In order to decide whether there is a cointegration relationship between the variables,

the F-test with these critical values is compared with other critical values. If the F-test value is greater than the critical upper bound I(1) values, the null hypothesis that there is no cointegration relationship between the variables is rejected. In this framework, the existence of a long-run cointegration relationship between variables is accepted. On the other hand, if it is accepted that there is a cointegration relationship between the variables, the variables are expected to converge to equilibrium in the long run and therefore, the model (3) is re-estimated by including the unrestricted error term (δECM) in the model.

$$\Delta EMP_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} \Delta EMP_{t-i} + \sum_{i=1}^{k} \alpha_{2i} \Delta LRE_{1t-i} + \sum_{i=1}^{k} \alpha_{3i} \Delta FC_{2t-i} + \delta ECM_{t-1} + \mu_t \quad (3)$$

The error correction term is a lagged value of the residuals of the model in which the long-run relationship is obtained. The error correction coefficient (δ) added to the model is expected to be both negative and statistically significant. The coefficient of this variable indicates how much of a short-run imbalance will be corrected in the long run. In addition, CUSUM and CUSUMSQ tests should be performed at this stage to determine whether the variables are stable or not.

Findings

1. Unit Root Test

In time series analyses, the stationarity properties of the series are examined first. At the same time, when applying the ARDL bounds test, the stationarity of the series should be stationary at level or stationary at first order. However, if the series are stationary at second order, the ARDL bounds test cannot be used in the study (Peseran, Shin and Smith, 2001). Extended Dickey Fuller (ADF) and Phillips-Perron (PP) unit root tests are used to test the stationarity of all variables used in this study. According to the results of the unit root tests, it is observed that all series are not stationary at level and become stationary when the series are differenced at first order. The unit root tests of the variables are shown in Table 1.

Table 1. Unit Root Test Results

Variable	Lag	ADF	Probability	Band	PP	Probability
EMP	*0*	*-1.61*	*0.45*	*1*	*-1.72*	*0.40*
ΔEMP	*0*	*-3.25*	*0.00*	*3*	*-3.10*	*0.00*
LRE	*0*	*-1.50*	*0.50*	*2*	*-1.46*	*0.52*
ΔLRE	*0*	*-4.87*	*0.00*	*2*	*-4.90*	*0.00*
FC	*0*	*-1.67*	*0.42*	*1*	*-1.69*	*0.41*
ΔFC	*0*	*-4.70*	*0.00*	*0*	*-4.70*	*0.00*

2. ARDL Bounds Test

The first stage of the ARDL model is to determine the appropriate lag length. For this purpose, the variables are tested with different lag combinations and the model that gives the lowest value according to the information criteria is selected as the appropriate model. In this context, according to the Akaike Information Criterion (AIC), the ARDL (2, 4, 1) model is selected as the appropriate model. The estimation results of this model are presented in Table 2.

Table 2. ARDL (2, 4, 1) Model Estimation Results

Variables	Coefficient	t-values	Probability
EMP(-1)	0.386785	1.892966	0.0950
EMP(-2)	-0.411368	-2.342160	0.0473
LRE	-0.422581	-1.966667	0.0848
LRE(-1)	-0.081708	-0.393619	0.7041
LRE(-2)	0.180166	0.900161	0.3943
LRE(-3)	0.282402	1.173772	0.2742
LRE(-4)	0.393864	1.509345	0.1696
FC	0.367662	2.012546	0.0790
FC(-1)	0.232930	1.543483	0.1613
C	26.06905	4.122153	0.0033
Diagnostic Tests			
R^2		0.944	
Adjusted R^2		0.881	
F statistic		15.094 (0.00)	
Autocorrelation		6.534 (0.03)	
Normality		2.803 (0.24)	
Variable Variance		10.313 (0.32)	
F Statistics Critical Limit Values for Determination of Long-Run Relationships			
Asymptotic Critical Values	**Calculated F statistic**	**Lower Limit I(0)**	**Upper Limit I(1)**
%10		2.915	3.695
%5	9.692	3.538	4.428
%1		5.155	6.265

Before proceeding with the ARDL test results, it would be better to explain some of the tests performed for the model. In this context, we can state that the R2 value of the estimated model is high, that is, the explanatory power of the model is at an acceptable level. According to the results of the Breusch-Pagan-Goldfrey test used to determine whether there is a problem of changing variance in the model, it is seen that there is no problem of changing variance in the model. Breusch-Goldfrey LM test was applied to determine whether there is an autocorrelation problem in the model and it was determined that there is no autocorrelation problem in the model. Finally, the residual terms of the model are normally distributed.After this stage, the existence of cointegration relationship between variables is tested. This test is performed regardless of whether the variables are I(0), I(1) or mutually cointegrated (De Vita and Abbott, 2002). In order to determine the existence of a long-run cointegration relationship between variables, the F-statistic (bounds test) value is used. In this context, the F-statistic value obtained (9.692) is greater than the upper critical value I(1) at 1%, 5% and 10% significance levels. Therefore, the null hypothesis of no long-run relationship between the variables is rejected. In other words, it is concluded that there is a long-run cointegration relationship between the variables used in the analysis. What needs to be done after this point is to find the long-run coefficients. The long-run coefficients obtained for the model are presented in Table 3.

Table 3. ARDL (2, 4, 1) Model Long and Short Run Coefficients

Long Run Coefficients			
Variables	**Coefficient**	**t-values**	**Probability**
LRE	0.343694	2.593034	0.0320
FC	0.586182	4.307491	0.0026
C	25.44357	7.213454	0.0001
Short Run Coefficients			
Variables	**Coefficient**	**t-values**	**Probability**
C	26.06905	4.122153	0.0033
EMP(-1)*	-1.024583	-5.845062	0.0004
LRE(-1)	0.352143	2.640207	0.0297
FC(-1)	0.600592	3.658385	0.0064
D(EMP(-1))	0.411368	2.342160	0.0473
D(LRE)	-0.422581	-1.966667	0.0848
D(LRE(-1))	-0.856432	-3.938988	0.0043
D(LRE(-2))	-0.676266	-3.122603	0.0142
D(LRE(-3))	-0.393864	-1.509345	0.1696
D(FC)	0.367662	2.012546	0.0790

In the context of the results obtained, it is seen that a 1% increase in the coefficient of gross fixed capital formation in Turkey in the long run increases employment by 0.58%. A 1% increase in the renewable energy coefficient, which constitutes the main objective of the study, causes a 0.34% increase in employment. In this case, it can be said that there is a positive relationship between renewable energy and employment. In order to determine the short-term relationship between the variables included in the analysis, an error correction model based on the ARDL approach was established and the results obtained are presented in Table 4.

Table 4. ARDL (2, 4, 1) Model Error Correction Model Estimation Results

Variables	Coefficient	t-values	Probability
D(EMP(-1))	0.411368	2.982070	0.0175
D(LRE)	-0.422581	-3.060129	0.0156
D(LRE(-1))	-0.856432	-4.998637	0.0011
D(LRE(-2))	-0.676266	-4.100202	0.0034
D(LRE(-3))	-0.393864	-2.568764	0.0332
D(FC)	0.367662	3.930792	0.0044
CointEq(-1)*	-1.024583	-7.301101	0.0001

The error correction coefficient (-1.024) obtained from the error correction model is negative and statistically significant as expected. This coefficient indicates that the error correction model, which corrects the imbalance in the short run, works properly. CUSUM and CUSUM-of-Square tests were performed to test the stability of the estimated ARDL (2, 4, 1) model, i.e. whether there is structural change. The visual test results of CUSUM and CUSUMQ tests are presented in Figure 3.

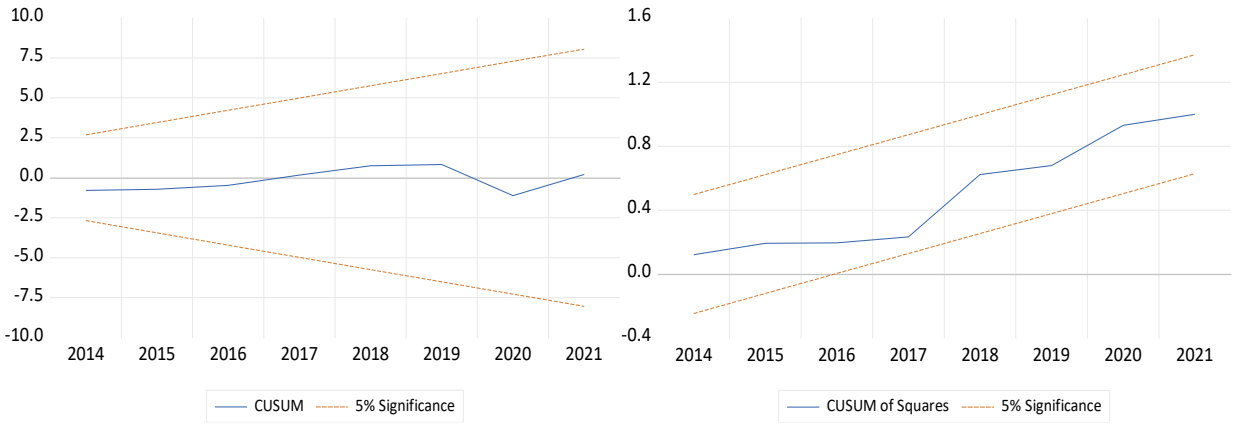

Figure 3. CUSUM and CUSUMQ Charts

It is seen that the parameters obtained in both CUSUM and CUSUMQ graphs are within the critical limits at 5% significance level. Therefore, it is seen that the parameters within the critical limits are stable and therefore the model is stable in the estimation period, i.e. there is no structural break.

Conclusion

The aim of this study is to explain the long-run relationship between renewable energy and employment in Turkey by using employment, renewable energy and gross fixed capital formation data for the period 2000-2021. In this context, ADF (Augmented Dickey-Fuller) and PP (Philips-Perron) unit root tests were applied to test whether the variables contain unit roots. According to the unit root test results, all series were found to be non-stationary at the level and therefore, all series were made stationary by taking their first order differences. On the other hand, in order to test whether there is a long-run cointegration relationship between the variables, the ARDL bounds test approach developed by Peseran, Shin and Smith (2001) was preferred.

In the context of the ARDL bounds test results obtained, it is seen that a 1% increase in gross fixed capital formation in Turkey in the long run increases employment by 0.58%. This result shows that the increase in the capital stock, which is the basis of Turkey's economic growth trend in the period under consideration, will lead to significant increases in Turkey's national income rate and will be effective in its economic growth. The increase in gross fixed capital formation also leads to an increase in employment. In this context, it can be said that the thesis of growth that does not create employment due to technological developments, which has taken an important place in the literature especially in the last few years, is not valid in Turkey.

When we look at the effect of renewable energy on employment, which constitutes the main purpose of the study, it is seen that a 1% increase in renewable energy causes a 0.34% increase in employment. In this case, it can be said that there is a positive relationship between renewable energy and employment. The main reason for this relatively low increase is that investments in renewable energy resources in Turkey have increased only in the last few years and the renewable energy sector is still a newly developing sector. However, it is thought that the renewable energy demand that will increase with Turkey's policies to reduce primary energy demand in the coming years and the significant increases in investments in renewable energy resources will create more effective results on employment.

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ÜÇ FARKLI YÖNTEMLE ÜRETİLEN n-CdS/p-Cu_2S GÜNEŞ PİLLERİNİN FOTOVOLTAİK ÖZELLİKLERİNİN İNCELENMESİ

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ÖZET

Bu çalışmada tek kristal CdS üzerine Cu ince filmi, kriyojenik etki yöntemi ile 200 K altlık sıcaklığında, klasik vakum buharlaştırma yöntemi ile 300 K altlık sıcaklığında ve kimyasal daldırma yöntemi kullanılarak elde edildi. CdS/Cu ikili yapısında heteroeklem oluşumu için örnekler 180°C'de 10 dakika süre ile ısıl işleme tabi tutularak n-CdS/p-Cu_2S güneş pilleri elde edildi. Alan emisyonlu taramalı elektron mikroskobu (FESEM) görüntüleri, 200 K altlık sıcaklığında elde edilen Cu katmanının soliton büyüme mekanizmasına uygun olarak 10-15 nm çaplı nanoparçacıklardan oluştuğunu gösterdi. n-CdS/p-Cu_2S güneş pili örneklerinde çalışma alanının tespiti için dalga boyuna göre duyarlılık spektrumu ölçüldü. Elde edilen sonuçlar 200 K altlık sıcaklığında üretilen n-CdS/p-Cu_2S güneş pilinin daha geniş dalga boyu aralığında fotovoltaik değerler ürettiğini gösterdi. n-CdS/p-Cu_2S güneş pilinin 12 hafta boyunca karanlık ve aydınlık ortamda (93 mW/cm^2) I-V ve C-V ölçümleri yapıldı. I-V ölçümlerinden açık devre gerilimi (Voc), kısa devre akımı (Isc), maksimum güç (Pmax), doldurma faktörü ve verimlilik değerleri hesaplandı. Hazırlanan güneş pilleri için en yüksek verim değeri 200 K altlık sıcaklığında 7. Haftada, 300 K altlık sıcaklığında ise 5. haftada elde edildi. C-V ölçümlerinden donör yoğunluğu (Nd) ve bariyer potansiyeli (Vbi) hesaplandı. 200 K altlık sıcaklığında üretilen güneş pili daha yüksek donör yoğunluğuna (1. hafta 2,99 x 10^{16} cm^{-3}) ve bariyer potansiyeli değerlerine (12. hafta 0,411 V) sahip olduğu görüldü. 200 K altlık sıcaklığında üretilen güneş pilinde daha yüksek fotovoltaik parametre değerlerinin Cu katmanında meydana gelen yüzey plazmon rezonans olayından kaynaklandığı düşünüldü. 12 haftalık süre sonunda 200 K ve 300 K altlık sıcaklıklarında oluşturulan güneş pillerinin bozulma oranı sırasıyla %51 ve %94 oldu.

Anahtar Kelimeler: CdS, Kriyojenik Etki, Solar Cell.

ABSTRACT

In this study, Cu thin film on single crystal CdS was obtained using the cryogenic effect method at 200 K substrate temperature, the classical vacuum evaporation method at 300 K substrate temperature and the chemical immersion method. For the formation of heterojunction in the CdS/Cu binary structure, the samples were subjected to heat treatment at 180°C for 10 minutes to obtain n-CdS/p-Cu_2S solar cells. Field emission scanning electron microscope (FESEM) images showed that the Cu layer obtained at 200 K substrate temperature consisted of nanoparticles with a diameter of 10-15 nm in accordance with the soliton growth mechanism. To determine the working area in n-CdS/p-Cu_2S solar cell samples, the sensitivity spectrum was measured according to wavelength. The results showed that the n-CdS/p-Cu_2S solar cell produced at 200 K substrate temperature produced photovoltaic values in a wider wavelength range. I-V and C-V measurements of the n-CdS/p-Cu_2S solar cell were made in dark and bright conditions (93 mW/cm^2) for 12 weeks. Open

circuit voltage (Voc), short circuit current (Isc), maximum power (Pmax), filling factor and efficiency values were calculated from I-V measurements. The highest efficiency value for the prepared solar cells was obtained in the 7th week at 200 K substrate temperature and in the 5th week at 300 K substrate temperature. Donor density (Nd) and barrier potential (Vbi) were calculated from C-V measurements. The solar cell produced at 200 K substrate temperature has higher donor density (1st week 2.99 x 10^{16} cm^{-3}) and barrier potential values (12th week 0.411 V). At the end of the 12-week period, the degradation rate of solar cells created at 200 K and 300 K substrate temperatures was 51% and 94%, respectively.

Keywords: CdS, Cryogenic Effect, Solar Cell.

1. GİRİŞ

Teknolojideki hızlı gelişmeler nedeniyle enerjiye olan talep artmaktadır. Öte yandan fosil yakıtların giderek tükenmesi ve küresel ısınmaya sağladığı olumsuz katkılar yenilenebilir enerji kaynaklarının üretilmesini ve incelenmesini önemli kılmaktadır. Yenilenebilir enerji kaynakları arasında güneş enerjisi önemli bir potansiyele sahiptir. Bu bağlamda araştırmacılar çalışmalarını güneş pilleri üzerine yoğunlaştırmışlardır. Ancak güneş pillerinde görülen en büyük sorun maliyetlerinin yanında kısa zamanda verimlerinin düşmesidir [1]. Günümüzde genellikle silikon (Si) wafer tabanlı teknoloji (birinci nesil), Si, CdTe, CIGS (ikinci nesil) ince film teknolojileri ve üçüncü nesil güneş pilleri (polimer, perovskite, boya duyarlı) gibi üç tür fotovoltaik cihaz bilinmektedir. Tüm çalışmaların temel amacı maliyetleri düşürmek ve verimliliği artırmaktır. Örneğin ikinci nesil güneş pilleri arasında yer alan n-CdS/p-Cu_2S heteroeklem güneş pillerinin teorik verim değerleri %24 olmasına karşın deneysel verimleri oldukça düşük olmaktadır [1]. Deneysel verim değerlerinin düşük olmasının nedeni hareketli bakır atomlarının Cu_2S katmanından CdS katmanına difüz olmasıdır [2]. Bakırın hareketliliği sonucu $Cu_{2-x}S$ fazı x değerine bağlı olarak sürekli değişmekte ve CdS yüzeyinin yakın bölgelerinde çok sayıda Cu_xS fazının türevlerini oluşturmaktadır. Bazı $Cu_{2-x}S$ yapılarının alabileceği yasak band aralığı değerleri, Cu_2S için Eg=1,2 eV, $Cu_{1,96}S$ için Eg=1,4 eV, $Cu_{1,8}S$ için Eg=1,5 eV ve CuS için Eg=2 eV'dir [1]. Bununla birlikte en yüksek verim ortorombik kalkosit yapıya sahip Cu_2S fazında görülmüştür [3]. Literatürde bakırın CdS'e hareketliliğinin durdurulması yönünde değişik çalışmalar yapılmıştır. Örneğin %1,6 verimle çalışan ve 4 ay aktivitesini koruyan CdS/Cu_2S fotovoltaik yapılar, CdS nano çubuklar ve Cu_2S nano kristaller kullanılarak hazırlanmıştır [4]. Yapılan başka bir çalışmada tek kristal CdS yüzeyini sodyum atomları ile katkılandırarak Cu_2S temas yüzeyinde düşük hareketli [Cu_i^+-V_{Cd}^-] kusur kompleksleri elde edilmiştir. Bu kusur komplekslerin bakır atomları için durdurucu elektriksel alan oluşturduğunu tespit edilmiştir [5].

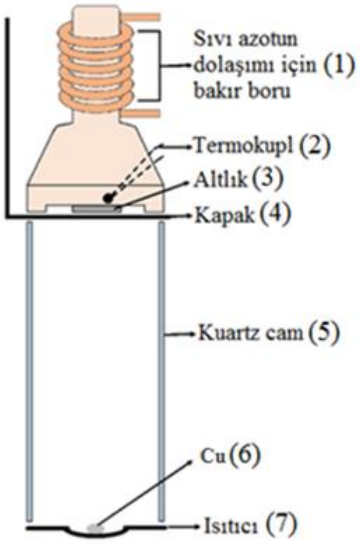
Yukarıda CdS/$Cu_{2-x}S$ güneş pilleri ile ilgili belirtilen olumsuzluklar ağırlıklı olarak Cu katmanının fotonlarla etkileşmesi sonucu pil yüzeyinde ve hacminde oluşan "foton alanından'' kaynaklandığı anlaşılmaktadır. Oysaki son yıllarda optoelektronik aygıtlar "plazmon alanı" prensibi temelinde üretilmektedir [6-8]. Bilindiği üzere yüzey plazmon rezonans olayı (SPR) metalik (Ag, Au, Al ve Cu gibi) nano parçacıklar temelinde oluşmaktadır [9-11]. Metal nanopartiküller arasında, bakır nanopartiküller, düşük maliyetleri (Au ve Ag'nin aksine) ve yeni optik, katalitik, mekanik, elektrik, manyetik ve ısı iletim özellikleri nedeniyle son zamanlarda oldukça ilgi çekmektedir [12]. Ayrıca bu olayın daha etkili olması için metalik katmanı oluşturan parçacıkların eşit boyutlu olması gerekmektedir. Plazmon rezonans absorbansı ve bant genişliği, partikül boyutuna ve şekline, çevreleyen ortamın dielektrik özelliklerine, konsantrasyona ve agregasyon durumlarına bağlıdır [13, 14].

Bu bağlamda "plazmon alanı" etkili fotovoltaik aygıtların üretiminde eşit parçacık boyutlu metalik nano yapılı katmanlar üreten yöntemler önem taşımaktadır. Bu çalışmada tek kristal CdS üzerine çöktürülmüş Cu katmanları iki farklı altlık sıcaklığında (200 K ve 300 K) ve kimyasal yöntemle gerçekleştirildi. Heteroeklem oluşum sonrası bu yeni uygulamanın (kriyojenik etki yönteminin) CdS/Cu_2S güneş pilleri üzerine olan etkisi incelendi.

2. MATERYAL VE METOT

Temel katman olarak özdirenç değeri ρ = 10 Ω-cm, kalınlığı d=2,5 mm olan hekzogonal yapılı (002) yönelimli tek kristal n-CdS kullanıldı. n-CdS için omik kontak olarak metalik indiyumdan yararlanıldı. Şekil l'de CdS/Cu ikili yapıların oluşumunda kullanılan kriyojenik etki buharlaştırma düzeneğinin şematik görünümü verildi [8]. Altlık sıcaklığı, ısı sensörü ile kontrol edildi. Altlıkların soğutulmasında sıvı azot kullanıldı. Cu katmanının oluşumunda %99,90 saflıkta (Sigma-Aldrich marka) Cu kullanıldı. Altlık sıcaklığı 200 K'e ulaştığında

buharlaşma süreci başlatıldı. Kuartz yapılı reaktörde Cu'ın doymuş buharı oluştuğunda pencere açıldı ve altlıkla doymuş buhar ortamının teması sağlandı. Böylece altlık yüzeyinde soliton büyüme mekanizması gerçekleşti ve altlık yüzeyi eşit boyutlu Cu nano kümeleri ile kapladı. Kimyasal yöntemde 0,1 M CuCl çözeltisi hazırlandı. Çözelti ısıtıcılı manyetik karıştırıcıda karıştırıldı ve 100 ^{O}C'ye kadar ısıtıldı. CdS altlık 100 ºC'de doymuş CuCl çözeltisine 10 saniye daldırılıp çıkarıldı ve ardından saf suya 10 saniye daldırıldı. Aynı işlem 2 defa tekrarlandı. Bu işlem ile CdS/Cu ikili yapısı oluşturuldu. Daha sonra elde edilen CdS/Cu ikili yapılar hava ortamında 180 ^{o}C 10 dakika süre ile tavlandı ve CdS/Cu_2S heteroeklem güneş pilleri oluşturuldu.

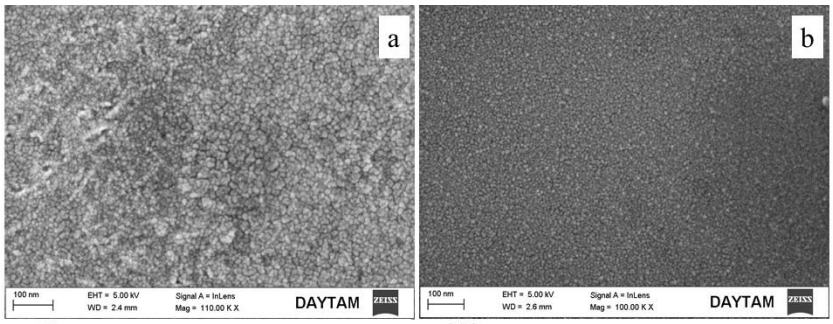


Şekil 1. Kriyojenik etki buharlaştırma düzeneğinin şematik görüntüsü.

CdS'in X-ışını kırınımı analizi Rigaku marka SmartLab X-ışını difraktometresi kullanılarak gerçekleştirildi. X ışını kaynağı olarak CuKα (λ=1,5408 Å) kullanıldı. Analiz oda sıcaklığında, $20^{O} \leq 2\theta \leq 80^{O}$ aralığında ve 0,02º'lik adımlar ile gerçekleştirildi. CdS/Cu_2S güneş pillerinin elektriksel ölçümleri oda sıcaklığında (300 K) Ivıum CompactStat.h10800 elektrokimyasal ölçüm cihazı kullanılarak gerçekleştirildi. Fotovoltaik ölçümlerde 93 mW/cm^2 gücünde Sciencetech marka SF150C model güneş simülatörü kullanıldı. Üretilen ince filmlerin FESEM görüntüleri Zeiss Sigma 300 cihazı kullanılarak alındı. Üretilen n-CdS/p-Cu_2S güneş pillerinin optik ölçümlerinde SpektraMax M5 UV-Vis. spektrofotometresi kullanıldı.

3. Bulgular

Şekil 2 a. 300 K ve b. 200 K altlık sıcaklıklarında cam yüzeyinde üretilen Cu ince filmlerin FESEM görüntüsü verildi. Şekilden görüldüğü üzere 300 K altlık sıcaklığında üretilen Cu katmanı farklı boyutlu adacıklardan oluşurken, 200 K altlık sıcaklığında elde edilen Cu katmanı eşit boyutlu nano parçacıklarla oluşmuştur. Ayrıca 200 K de hazırlanan Cu katmanı daha homojen bir yüzeye sahiptir. 200 K altlık sıcaklığında Cu katmanının eşit boyutlu kümelerden oluşması bu katmanın soliton büyüme mekanizması ile büyüdüğünü göstermektedir [8-10].



Şekil 2. a) 300 K, b) 200 K için cam yüzeyinde üretilen Cu ince filmlerin FESEM görüntüleri.

Şekil 3'de 200 K, 300 K altlık sıcaklıklarında ve kimyasal yöntemle üretilen n-CdS/p-Cu_2S güneş pillerine ait aydınlık ortamda (93 mW/cm^2) ölçülen I-V grafikleri verildi. 12 hafta boyunca aydınlıkta yapılan I-V ölçümlerinden kısa devre akımı (I_{sc}), açık devre gerilimi (V_{oc}), doldurma faktörü (FF), maksimum güç (P_{max}) ve hücre verimi (η) değerleri hesaplandı. Açık devre gerilimi (V_{oc}), sıfır akımda meydana gelen maksimum voltajdır. Kısa devre akımı (I_{sc}) ise sıfır voltajda hücreden elde edilen akımdır. Güneş pilindeki toplam akım,

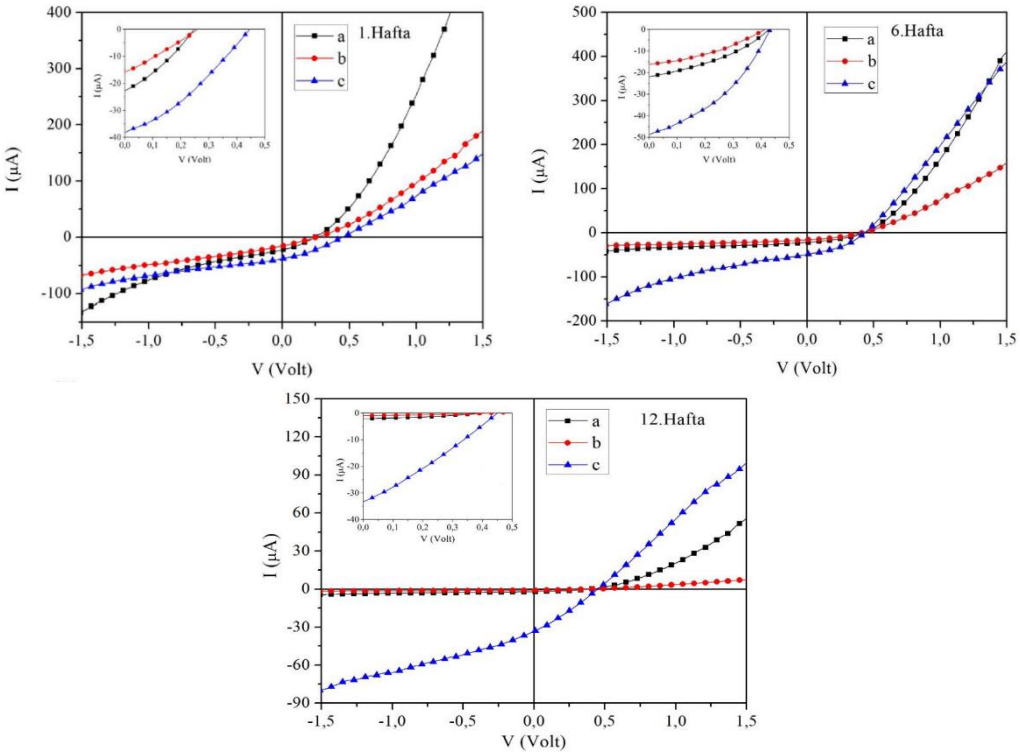
$$I = -I_{ph} + I_0[\exp(eV/nkT) - 1] \quad (1)$$

denklemi ile ifade edilir. Burada I_0 doyma akımı, n idealite faktörü, k Boltzman sabiti, T mutlak sıcaklık ve I_{ph} foto akımdır.

Güneş pillerinde aydınlık ortamda ölçülen I-V karakteristik eğrileri kullanılarak fotovoltaik parametreler hesaplandı. Doldurma faktörü (FF), 0 ila 1 arasında değişen ve bir hücrenin V_{oc} ve I_{sc}'ye göre performansını ifade eden bir değerdir. Doldurma faktörü (FF) ve foto dönüşüm verimliliği (% η) aşağıdaki denklemler kullanılarak hesaplandı [15].

$$FF = \frac{I_{max} \times V_{max}}{I_{sc} \times V_{oc}} \quad (2)$$

$$\eta(\%) = \frac{I_{max} \times V_{max}}{P_{in}} \times 100 \quad (3)$$



Şekil 3. Farklı yöntemle üretilen güneş pillerinin 1., 6. ve 12. haftalara ait aydınlık ortam I-V grafikleri a) Kimyasal yöntem, b)300 K ve c) 200 K.

Tablo 1'de ışık altında I-V ölçümlerinden hesaplanan kısa devre akımı (I_{sc}), açık devre gerilimi (V_{oc}), maksimum güç (P_{max}), doldurma faktörü (FF) ve hücre dönüşüm verimliliği (η) değerleri verildi. Tablodan görüldüğü üzere en yüksek I_{sc}, V_{oc}, P_{max}, FF ve η değerleri (I_{sc}=4,924 x10^{-5} A, V_{oc}=0,43 V, P_{max} = 8,732 x10^{-6} W, FF=0,4124 ve η=0,1343) 200 K altlık sıcaklığında üretilen güneş piline aitken en düşük değerler 300 K altlık sıcaklığında üretilen güneş piline aittir. Güneş pilleri incelendiğinde en hızlı bozulma sürecinin 300 K altlık sıcaklığında üretilen güneş pilinde meydana geldiği görüldü. En yavaş bozulma sürecinin ise 200 K altlık sıcaklığında üretilen güneş piline ait olduğu görüldü. 300 K altlık sıcaklığında üretilen güneş pillinde ise Cu katmanının farklı boyutlu adacıklar ile kaplanması ve taneciklerin hareketliliğinin fazla olması sonucu

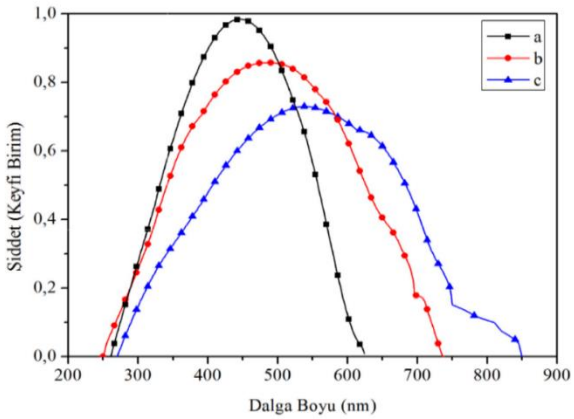
difüzyonun daha hızlı gerçekleşmesi bozulma sürecini hızlandırdığı düşünülmektedir. Islam ve Haque, (1982) vakum buharlaştırma yöntemi ile üretilen n-CdS/p-Cu_2S güneş pilinde açık devre gerilimlerini 0,45-0,47 V ve kısa devre akım yoğunluklarını 14-16 mA.cm^{-2} ve hücre verimleri %4,8 ile %5 arasında bulmuştur [16]. Taur vd. (2012) kimyasal yöntem ile üretilen CdS/Cu_2S güneş pilinin dönüşüm verimliliğini tavlanmış numunede η=0,24 tavlanmamış numunede ise η=0,09 olarak bulmuştur [17]. Lu vd., (2019), kimyasal buhar biriktirme yöntemi ile üretilen n-CdS/p-Cu_2S güneş pilinin kısa devre akımı, açık devre gerilimi, doldurma faktörü ve güç dönüşüm verimliliğini, sırasıyla 0,152 nA, 0,245 V, 0,445 ve %0,405 olarak hesaplamıştır [18].

n-CdS/p-Cu_2S güneş pillerinin C-V ölçümleri, -0,5 V ve +0,5 V aralığında 1000 Hz frekansta oda sıcaklığında yapıldı. Bu ölçümlerde güneş pillerinin eklem engel potansiyeli (V_{bi}) ve donör yoğunluğu (N_d) hesaplandı. Üretilen güneş pillerine ait hesaplanan eklem engel potansiyeli ve verici yoğunluğu değerleri Tablo 1'de verildi. Tabloda görüldüğü üzere en yüksek verici yoğunluğu değeri ($5{,}59x10^{16}$ cm^{-3}) 200 K altlık sıcaklığında üretilen güneş piline aitken en düşük değer ($3{,}81x10^{11}$ cm^{-3}) 300 K altlık sıcaklığında üretilen güneş piline aittir. Eklem engel potansiyeli değerleri 200 K altlık sıcaklığında üretilen güneş pilinde en yüksek (0,411 V) iken 300 K altlık sıcaklığında üretilen güneş pilinde en düşük (0,025 V) değerdedir. 12 haftalık süre takip edildiğinde verici yoğunluğu değerleri azalırken eklem engel potansiyeli değerleri artmaktadır. Lepley vd. (1979) tarafından vakum buharlaştırma yöntemi ile üretilen CdS/Cu_2S heteroekleminde yapılan C-V ölçümleri ile başlangıç verici yoğunluğu $1{,}8x10^{17}$ cm^{-3} olarak bulunmuştur. Ölçümler 120 gün boyunca devam etmiş ve verici yoğunluğunun azaldığı görülmüştür. Vericilerin alıcılar tarafından aşırı derecede kompanse edilmesi sonucu engel potansiyelinin artacağı belirtilmiştir [8].

Tablo 1. Güneş pillerinde ölçülen elektriksel parametrelerin değerleri

Ölç.		I_{SC} (A)x10^{-5}	V_{OC} (V)	P_{max} (W)x10^{-6}	FF	η (%)	N_d (cm^{-3})	V_{bi} (V)
	K.Y	2,273	0,24	1,763	0,3232	0,0271	$1{,}43x10^{16}$	0,226
1.Haf.	**300K**	1,584	0,25	1,124	0,2840	0,0173	$5{,}30x10^{15}$	0,025
	200K	3,818	0,44	5,559	0,3309	0,0855	$5{,}59x10^{16}$	0,232
	K.Y	2,188	0,42	3,402	0,3702	0,0523	$3{,}02x10^{15}$	0,290
6.Haf.	**300K**	1,617	0,41	2,438	0,3677	0,0375	$1{,}69x10^{15}$	0,265
	200K	4,924	0,43	8,732	0,4124	0,1343	$3{,}80x10^{16}$	0,385
	K.Y	0,210	0,40	0,306	0,3640	0,0047	$3{,}55x10^{13}$	0,321
12.Haf	**300K**	0,098	0,42	0,141	0,3428	0,0022	$3{,}81x10^{11}$	0,315
	200K	3,302	0,44	4,363	0,3003	0,0671	$2{,}99x10^{16}$	0,411

Şekil 4'de 3 farklı yöntem ile üretilmiş n-CdS/p-Cu_2S heteroeklemlerin dalga boyuna göre duyarlılık spektrumları verildi. Şekilden görüldüğü gibi 200 K altlık sıcaklığında üretilen güneş pili en geniş çalışma alanına sahiptir



Şekil 4. Farklı yöntem ve farklı altlık sıcaklıklarında üretilen 180°C'de 10 dakika tavlanmış n-CdS/p-Cu2S güneş pillerinin dalga boyuna göre duyarlılık spektrumları a) Kimyasal yöntem, b) 300 K ve c) 200 K

4. Sonuçlar

Yapılan bu çalışmada termal buharlaştırma yöntemi ile 200 K ve 300 K altlık sıcaklıklarında ve kimyasal yöntemle n-CdS/p-Cu_2S güneş pilleri üretildi. 200 K ve 300 K altlık sıcaklıklarında üretilen Cu ince filmin FESEM analizi yapıldı. Cu ince filmin FESEM analizinde 300 K altlık sıcaklığında üretilen Cu katmanların adacık büyüme mekanizması ile gerçekleştiği 200 K altlık sıcaklığında ise Cu katmanının soliton büyüme mekanizması ile oluştuğu görüldü. Engel yüksekliği değerlerine bakıldığında 200 K altlık sıcaklığında üretilen güneş pilinin en yüksek değere sahip olduğu görüldü. Bununla birlikte en düşük engel yükseklik değeri 300 K altlık sıcaklığında üretilen güneş pilinde görüldü. Yüzey durumları ise engel yüksekliğinde artışa neden olduğu görüldü. En yüksek verici yoğunluğu ve engel potansiyeli değerleri 200 K altlık sıcaklığında üretilen güneş pilinde tespit edildi.12 haftalık süreç sonunda en hızlı bozulma 300 K altlık sıcaklığında üretilen güneş pilinde olmuştur.

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EXPERIMENTAL SETUP FOR INVESTIGATING THE PERFORMANCE OF PHOTOVOLTAIC PANELS UNDER DIFFERENT CLIMATE CONDITIONS

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ABSTRACT

The increasing demand for energy has increased the interest of investors in the use of renewable energy sources. In this context, the importance of power plants that produce electrical energy from the sun has increased. Environmental factors affecting panel efficiency play an important role in power plants where photovoltaic panels are used. It is known that the electrical energy production of photovoltaic panels varies depending on parameters such as heat, light, humidity, wind speed, and dust. Testing photovoltaic panels in real-time under all climatic conditions and different conditions is a long-term and costly application. Instead, it is much easier and more cost-effective to measure the output energy of photovoltaic panels by performing experiments under conditions where heat, light, humidity, wind speed and dust amount can be controlled. For this purpose, a laboratory-scale experimental setup was prepared using fiber material with dimensions of 1mx1mx1m. With the prepared mechanism, it is possible to perform experiments at ambient temperatures between 25°C and 45°C and at different percentages of humidity. Ambient temperature was provided by a Quartz heater placed inside the cabin by a PID-controlled electronic circuit. A 1000W halogen bulb was used as the light source. It is also possible to perform wind tests at different speeds between 3km/h and 27km/h by means of a DC motor with PID speed control circuit. It is also possible to conduct dusting experiments in the cabin using dust samples taken from places with different geographical characteristics. Current, voltage and panel temperature data obtained from the sample photovoltaic panel placed in the experimental setup prepared for different climatic conditions can be measured and recorded at 5-second intervals. For this purpose, a software that can provide fast results has been developed in accordance with the mechanism. In the laboratory environment, by changing the temperature, humidity, amount of dust in the air and wind speed parameters under controllable conditions, the effect of the amount of dust accumulated on the sample panels on the electrical energy produced can be observed. With this developed mechanism, the effect of dust samples of the location of solar power plants established or to be established in regions with different geographical characteristics on the electric current produced by the panel can be observed. It is thought that this established mechanism will be of great benefit in estimating panel efficiency in photovoltaic studies to be carried out in the laboratory environment.

Keywords: Photovoltaic panel, Photovoltaic panel efficiency, The experimental setup

INTRODUCTION

Today, the demand and interest in renewable energy sources, which are developing as an alternative to fossil fuels due to the increasing energy need and the obligations imposed by the Paris Climate Agreement, are increasing day by day. Among renewable energy sources, especially the significant decrease in the installation costs of solar energy systems has brought Photovoltaic (PV) applications to the forefront. In our country, the installed capacity of electricity based on solar energy until July 2022 is 8,479 MW and the share of this amount in total electricity generation is 8.35% in the reports published by the Ministry of Energy.

(https://enerji.gov.tr/eigm-yenilenebilir-enerji-kaynaklar-gunes 2023). The increasing demand for energy has increased the interest of investors in the use of renewable energy sources. In this context, the importance of solar power plants has increased. In power plants where photovoltaic panels are used, environmental factors affecting panel efficiency play an important role. It is known that photovoltaic panels differ in the electrical energy they produce depending on parameters such as heat, light, humidity, wind speed, and dust (Fouad et al., 2017).

Especially for Solar Power Plants (SPPs) located in the Central Anatolia and Southeastern Anatolia regions of our country, which is located in the arid climate zone, dusting is an important problem during the dry summer months. It has been pointed out in the literature that energy losses due to pollution can reach up to 15%, especially for regions where the summer months are dry and dusting is high due to agricultural activities (Deniz, 2013). Using the catalog data of the PV panel, the equivalent circuit of the panel was modeled in PSIM and MATLAB programs and the effects of temperature and solar radiation changes on PV panel power were examined and it was seen that low temperatures and high solar radiation intensities are more suitable for the power values obtained from PV panels. (Karanfil at al.2016). Since the permeability of solar cells due to dust accumulation on the PV cell surface will be greatly reduced by the accumulated dust particles, it has been proven by experimental study that it will significantly reduce PV power efficiency (Zhao at all 2021).

With the test setup to be prepared, the performance of the PV panels to be produced using parameters that cannot be controlled in real environment (temperature, humidity, air flow rate, luminous flux and dust size) will be evaluated compared to reference samples.

MATERIALS AND METHODS

There are many factors affecting the average annual energy gain from PV panels.. These factors can be listed as climate, temperature, pollution, shading, mismatch, inverter efficiency, age, etc. Testing photovoltaic panels in real-time environments in all climatic conditions and under different conditions is both a long-term and costly application. Instead, it is much easier and cost-effective to measure the output energy of photovoltaic panels by performing experiments under conditions where the amount of heat, light, humidity, wind speed and dust can be determined. For this purpose, a laboratory scale 100cmx100cmx100cmx100cm sized fibre material was used to design an experimental setup.

Establishment of laboratory scale test set-up

It is possible to perform experiments at ambient temperature between 25°C and 45°C and at different percentages of humidity. The ambient temperature was provided by a PID controlled electronic circuit with a Quartz heater placed in the cabinet. 1000W halogen bulb was used as light source. It is also possible to perform wind tests at different speeds between 3km/h and 27km/h by means of a DC motor with PID speed control circuit. The desired climatic conditions in the experimental setup created in the laboratory were controlled with Ardunio Mega2560. A Luxmeter (UT383S) was used to determine the amount of radiation and an Anemometer (UT363) was used to measure the wind speed. In addition, it is possible to perform dusting experiments in the cabin by using dust samples taken from places with different geographical characteristics. In order to test the electrical data of PV cells, the inclination angle of the platform where we will place the cells is taken as 32.08°. This value is an angle value recommended as a result of optimum slope studies for Konya (Arslan, 2022). The experimental setup is shown in Figure 1.

Figure 1. Laboratory-scale test set-up

The data to be obtained from this experimental setup is the basic data for the models to be created for real environment experiments.

Data Reading and Recording

With the TM4C1294 microcontroller based DAQ system produced by Texas Instruments, a laboratory test setup has been established where data such as current, voltage, temperature, humidity, wind speed can be collected in real time (Figure 2).

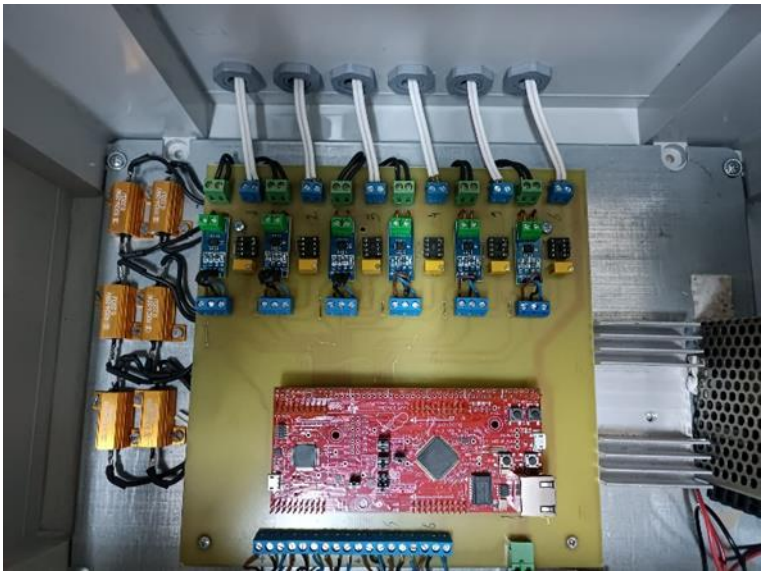

Figure 2. Data reading system

The current, voltage and panel temperature data obtained from the sample photovoltaic panel placed in the experimental setup prepared for different climatic conditions can be measured and recorded at 5-second intervals. For this purpose, a software that can get fast results has been implemented in accordance with the setup. Thanks to this software, it was possible to monitor the amount of electrical energy produced by each

panel and to compare the performance of different PV panels under real environment. The visual of the software is shown in Figure 3.

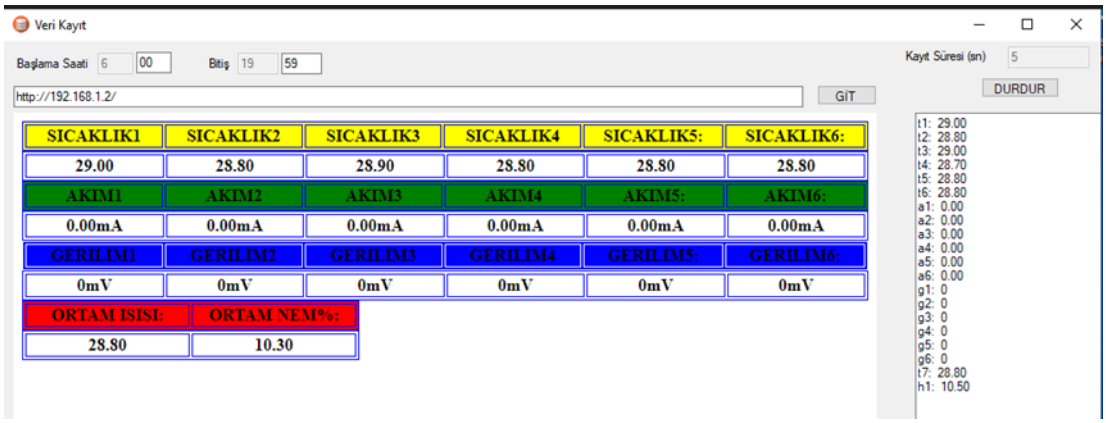

Figure 3. Programme developed for data recording system

FINDINGS AND DISCUSSION

Experiments with different temperature, humidity, wind speed and dust amount were carried out in the laboratory environment. The efficiency values of PV cells were obtained by utilizing the current and voltage data obtained from these experiments. When the temperature, humidity and wind speeds determined for the experiments were reached, the current and voltage values of the PV cells were recorded before throwing dust into the cabin and the initial efficiencies were calculated based on these values. Then, the inside of the cabinet was dusted with the determined amount of dust and after an average of one hour, current and voltage values were taken again, and the efficiency was calculated. Tables and graphs of PV cell efficiencies are given in Table 1 and Figure 4. Equation (1) was used for efficiency calculations.

$$\eta = Pmax/((G*S))*100 \quad (1)$$

$$Pmax = V_{OC} * I_{SC} \quad (2)$$

η : Yield

P_max : Maximum power of the PV cell (W)

G : Amount of radiation to which the PV cell is exposed (W/m2)

S : PV cell area (m2)

V_{OC} : Open circuit voltage (V)

I_{SC} : Short circuit current (A)

Table 1. Experimental results of PV cell

Experiment no.	Temp.°C	Hum. (%)	Dust Amount g/m3)	Wind Speed (km/h)	Dust Acumulation PV1 (mg)	Dust Acumulation PV2 (mg)	PV1 Yield (İnitial Values)	PV1 Verim (End Values)
1	40	40	5	27,7	4	2	11,41	10,04
2	25	80	0,5	7,3	12	5	12,24	10,22
3	32,5	60	0,5	17	6	2	11,06	9,87
4	25	40	5	27,7	10	4	36,84	34,02
5	25	80	5	7,3	44	31	35,25	31,51
6	32,5	60	2,5	17	45	35	34,93	31,87
7	25	40	5	7,3	40	25	34,78	31,99
8	40	40	0,5	7,3	5	3	31,69	29,51
9	40	60	2,5	17	43	35	31,91	30,23
10	40	40	5	7,3	15	9	24,91	17,95
11	40	80	5	7,3	30	19	21,91	19,28
12	32,5	60	2,5	17	11	7	37,12	30,36
13	40	80	0,5	7,3	4	1	31,84	29,04
14	32,5	80	2,5	17	26	19	32,85	30,86
15	32,5	40	2,5	17	23	17	33,81	32,06
16	32,5	60	2,5	27,7	5	1	27,50	25,30
17	40	80	0,5	27,7	3	1	26,17	25,10
18	25	80	5	27,7	25	20	29,40	26,76
19	32,5	60	5	17	71	62	28,87	26,64
20	32,5	60	2,5	27,7	48	40	27,47	23,25
21	25	60	2,5	17	34	30	25,63	23,04
22	32,5	60	2,5	17	15	12	25,28	22,68
23	32,5	60	2,5	17	20	13	29,86	25,55
24	40	80	5	27,7	4	1	29,73	28,45
25	40	40	0,5	27,7	3	1	33,25	30,40
26	32,5	60	2,5	7,3	44	38	28,03	25,45
27	32,5	60	2,5	17	28	22	28,44	26,98
28	25	40	0,5	7,3	14	6	33,24	31,70
29	25	80	0,5	27,7	17	12	31,59	26,13
30	32,5	60	2,5	17	32	27	27,89	26,43
31	25	40	0,5	27,7	3	1	31,84	29,79
32	32,5	60	2,5	17	24	15	25,97	24,21

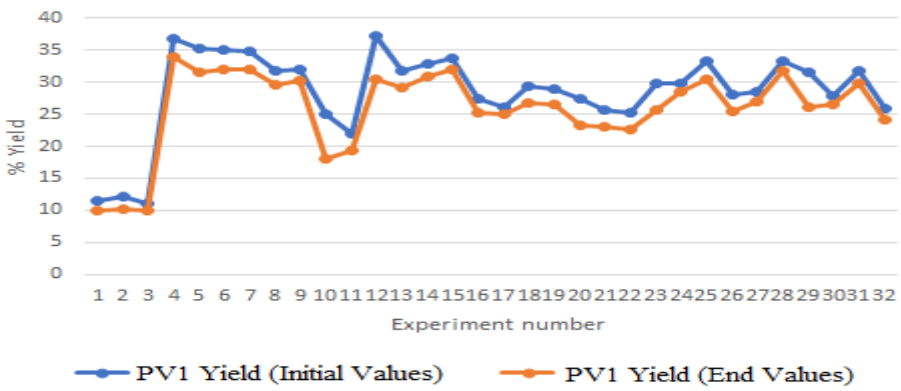

Figure 4. PV 1 Initial and final efficiencies

CONCLUSION AND RECOMMENDATIONS

Experiments with different temperature, humidity, wind speed and dust amount were carried out in the laboratory environment. The efficiency values of PV cells were obtained by utilizing the current and voltage data obtained from these experiments. When the temperature, humidity and wind speeds determined for the experiments were reached, the current and voltage values of the PV cells were recorded before throwing dust into the cabin and the initial efficiencies were calculated based on these values. Then, the inside of the cabinet was dusted with the determined amount of dust and after an average of one hour, current and voltage values were taken again, and the efficiency was calculated.

In the laboratory environment, the effect of the amount of dust accumulated on the sample panels on the electrical energy produced can be observed by changing the temperature, humidity, amount of dust in the air and wind speed parameters under controllable conditions. With this developed device, the effect of the dust samples of the location of the solar power plants installed or to be installed in regions with different geographical characteristics on the electric current generated by the panel can be observed. It is thought that this device will be of great benefit in the estimation of panel efficiency in photovoltaic studies to be carried out in the laboratory environment.

Thanks, and Information Note

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THE EFFECT OF SOIL SAMPLES COLLECTED FROM SOLAR POWER PLANTS IN KONYA PROVINCE ON PHOTOVOLTAIC PANEL EFFICIENCY

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ABSTRACT

One of the important factors affecting the power losses of photovoltaic panels is stated in the literature as dusting. Dusting can be expressed as the accumulation of dust particles in the air on the surface of the object. The most important factor affecting the amount of dust accumulation on the surface of the photovoltaic panel is the size and chemical content of the dust in the area where the panel is located. Three different mechanisms are proposed for dust deposition on the surface. These are gravitational sedimentation, inertial or turbulent deposition and Brownian motion, respectively. Dust deposition at the surface is generally dependent on particle size and wind speed. Very small dust particles (~1 µm in diameter and smaller) are randomly distributed in the environment and tend to be entrained by air movements. Very large particles (dust particles ~100 µm and larger) are governed by gravity and settle rapidly out of the air, independent of airflow. Medium-sized particles (on average ~10 µm in diameter) are influenced by their own mass and airflow. In this context, the size distribution and chemical structure of the dust particles in the panel environment affect the amount of dusting. In this study, we tried to increase the consistency of the experiments by collecting real dust samples from solar power plants (SPPs) in Konya and its region. For this purpose, dust samples were collected from 4 different SPPs in and around Konya province. The chemical and physical properties and size distributions of the collected samples were determined by XRD, SEM, FTIR and EDX analysis. It is important that the samples are collected in the real environment for the consistency of the experimental data. The effect of the collected powder samples on the panel yields was investigated in the experimental setup built in our laboratory. In the experimental setup, the amount of dust accumulation and efficiency losses on the sample panel, as well as the % transmittance changes of the sample lamellas were examined at conditions had controllable temperature, humidity, dust amount in the air and wind speed parameters in the laboratory environment. The results show that beyond the amount of dust deposition, the size of the dust has significant effects on efficiency losses and light transmittance.

Keywords: Photovoltaic panel, Photovoltaic panel efficiency, Dust Type, Dust Size.

INTRODUCTION

There are many factors affecting the average annual energy gain from PV panels. These factors can be listed as climate, temperature, pollution, shading, mismatch, inverter efficiency, age, etc. (Fouad et al., 2017; Meral & Diner, 2011). Especially pollution is an important factor affecting the amount of electrical energy produced from PV panels (Oh et al., 2016). Fouling can be defined as the blocking of part of the sunlight due to the presence of dirt or dust, and therefore causing significant losses in the power generated due to the dispersion of sunlight on the surface of the solar panel. The annual energy loss factor due to pollution is accepted in the literature as 0.93 (Fouad et al., 2017). In other words, only 93% of the maximum energy that can be produced can be produced and 7% is lost due to pollution. Figure 1 shows the amount of dust accumulated on the PV panel.

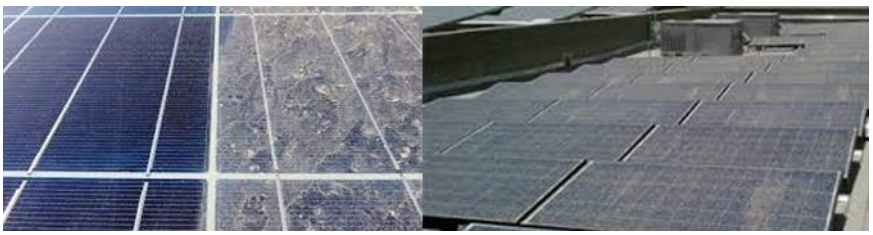


Figure 1. Dust accumulated on PV panels

Considering the annual electricity generation for our country, 7% loss corresponds to 593 MW energy. This amount means inefficient use of the existing potential. In addition, the structure, size, and dusting amount of dust particles that cause contamination affect the amount of energy loss due to contamination of the PV panel (Abderrezek and Fathi, 2017; El-Shobokshy and Hussein, 1993). One of the important points underlined in the literature is that the amount of yield losses in PV panels due to pollution depends on factors such as climate (rainfall, day and night temperature difference, etc.), geography (soil type, proximity to rivers and lakes) and socioeconomic reasons (human activity, distance from agricultural and industrial areas, etc.). When the researches conducted in the literature for Konya province and its surroundings are examined, only a Master's Thesis including performance analysis for 1 MWp grid connected SPP located in Konya Organised Industrial Zone was conducted and dusting losses were also included in the scope of the thesis. In the thesis, it was reported that dust remained on the surface even after rain and caused significant energy recovery losses (Sadıkoğlu, 2018).In this study, the effect of the size distribution and chemical structure of the dust particles in the environment where the panel is located on the amount of dusting was examined. In this study, it was tried to increase the consistency of the experiments by collecting real dust samples from SPPs in Konya and its region.

MATERIALS AND METHODS

Dust samples were collected from 4 SPP sites in Konya province. The regions where dust samples were collected are shown in Figure 2. While selecting these regions, proximity, quantity and duration were taken into consideration. For these reasons, 4 regions were analysed. The location of the collected samples are numbered and circled in yellow colour in Figure 2. The chemical and physical properties and size distributions of the collected samples were determined by XRD, SEM, FTIR and EDX analyses.

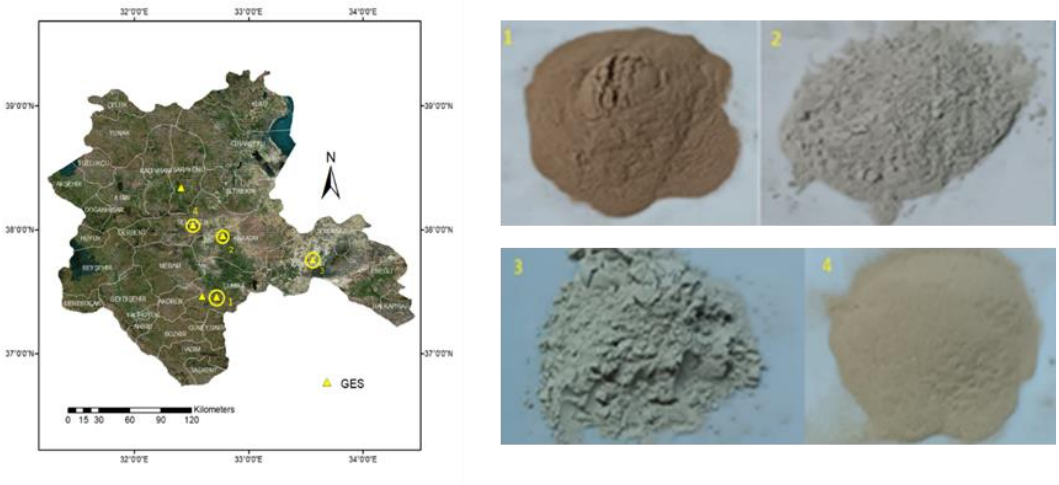


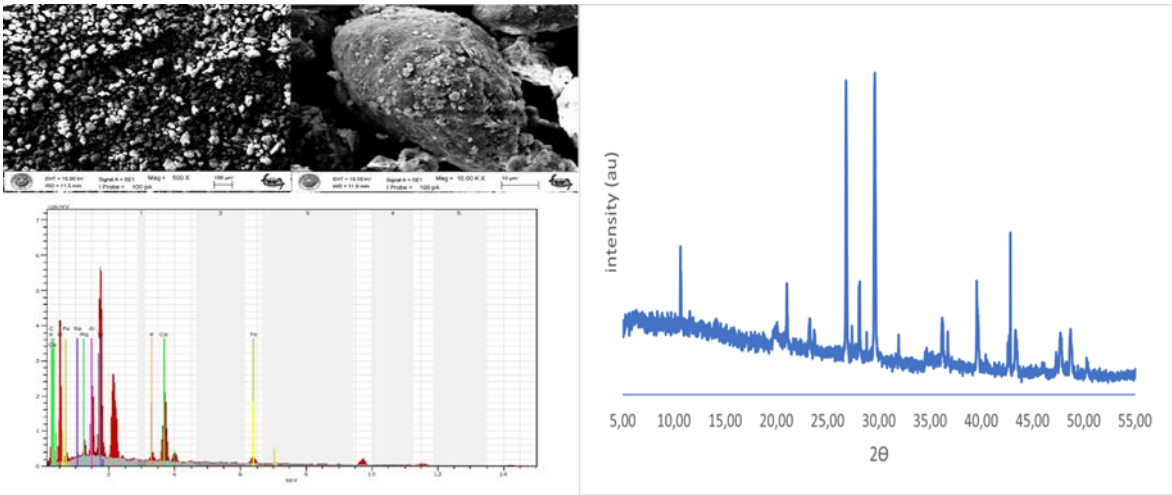
Figure 2. Dust samples taken from four different locations

FINDINGS AND DISCUSSION

Physical characterisation studies for dust samples

As can be seen in the SEM image and EDX spectra of powder sample 1 at two different magnifications, the powder particles are not homogeneous. In Figure 3.a, it consists of large dust particles ranging between 10-60 µm and dust particles ranging between 1-3 µm in size. In the EDX analysis of powder sample No. 1, peaks belonging mainly to Ca, Si and Al elements were observed. In the sample, 65.33% oxygen, 6.13% Calcium, 7.11% Silicon, 16.04% Carbon, 2.57% Aluminium and 1.35% Iron were detected by mass. The high amounts of Carbon and Oxygen indicate that the CO_3 content of the powder sample is high.

XRD spectrum of powder sample 1 is shown in Figure 3.b. In the XRD spectrum of sample number 1, there are 3 different crystal lattices that match the mineral library of the device. Three different minerals were identified in the sample as phyllo pyrite (zeolite), quartz and calcite. In addition to these minerals, classification was detected in the sample.

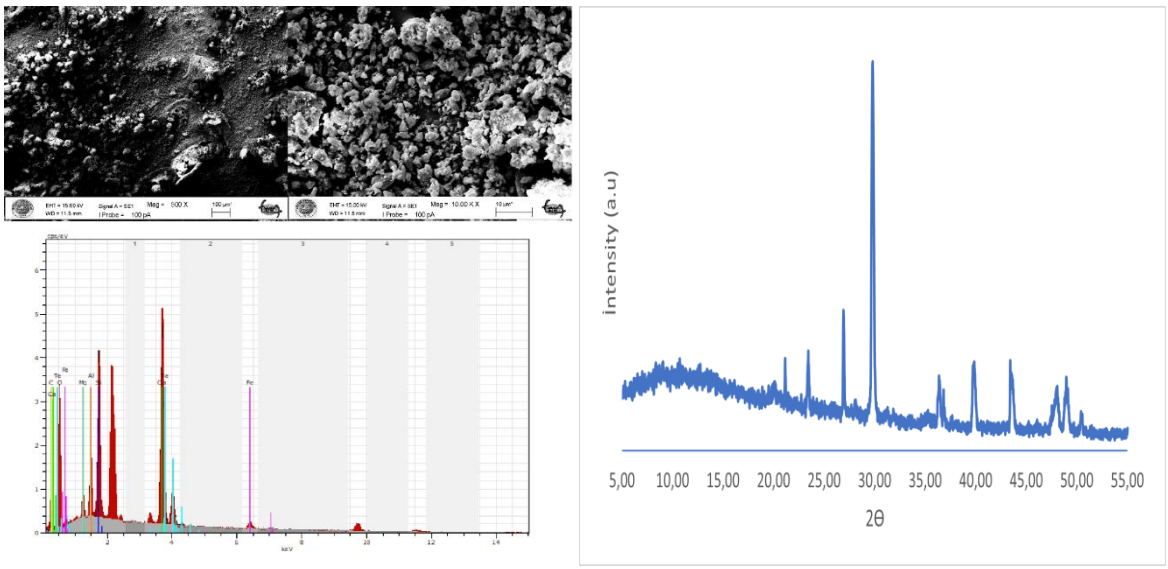


(a) (b)

Figure 3.(a) SEM images and EDX spectrum of powder sample 1, (b) XRD spectrum of powder sample 1.

In Figure 4.a, it is seen from the SEM images of dust sample No. 2 at two different magnifications that the sample is mostly composed of small, grained dust particles. The sample consists of powder particles ranging between 1.5-13 µm. In EDX analysis of sample 2, peaks belonging mainly to Ca, Si and Al elements were observed. The sample contains 53.22% Oxygen, 18.33% Calcium, 7.09% Silicon, 10.49% Carbon, 2.44% Aluminum and 1.08% Magnesium by mass. Particularly noteworthy in this sample is the presence of 4.91% Tellurium element. The high amounts of Carbon and Oxygen for this sample indicate that the CO_3 content of the powder sample is high.

In the XRD spectrum of powder sample 2 in Figure 4.b, two different crystal lattices were detected, and these minerals are thought to be calcite and quartz minerals by comparing with the minerals in the library of the device. For this sample, it was determined that the amount of calcite was quite high mineralogically.

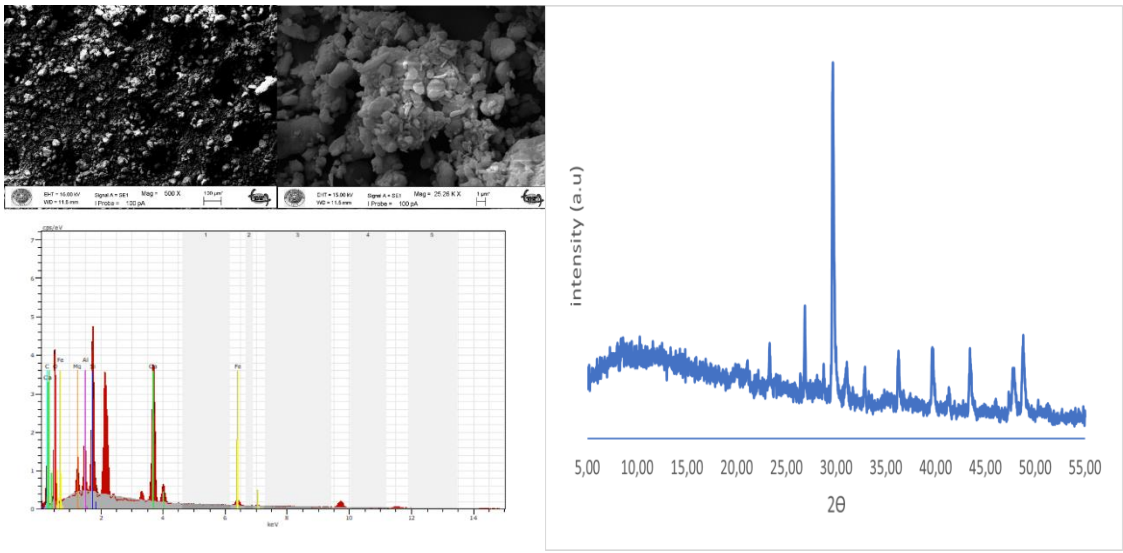


(a) (b)

Figure 4.(a) SEM images and EDX spectrum of dust sample no. 2, (b) XRD spectrum of dust sample no. 2.

The SEM images and EDX spectra of dust sample No. 3 taken at two different magnifications are a mixture of dust particles with sample sizes ranging between 22-65 µm and smaller dust particles. EDX analysis of powder sample No. 3 showed peaks mainly belonging to Ca, Si and Al elements (Figure 5.a).

In the comparison of the XRD spectrum of the powder sample number 3 with the help of the device's library, calcite and quartz minerals were detected in the powder sample number 3 as in the dust sample number 2, and it is seen that calcite is the dominant mineral (Figure 5.b).



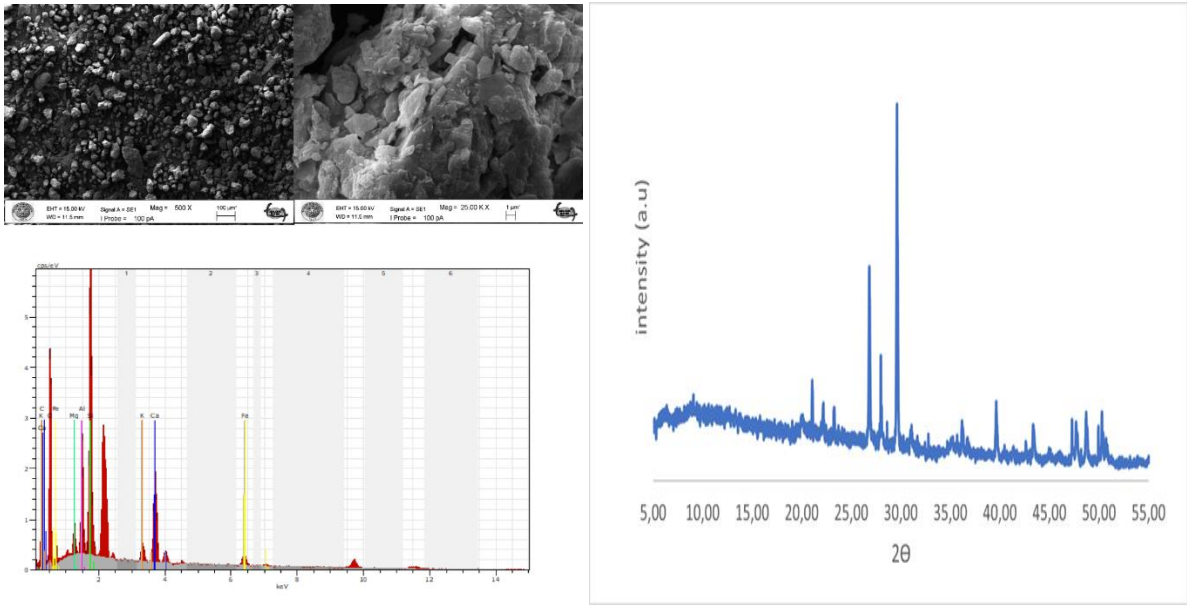
(a) (b)

Figure 5. (a) SEM images and EDX spectrum of dust sample 3, (b) XRD spectrum of dust sample 3

SEM images and EDX spectra of dust sample No. 4 at two different magnifications are shown in Figure 6.a. The sample consists of powder particles ranging in size from 17.154-98.08 µm. It is seen that the powder particles are not completely monolithic at higher magnifications but are aggregates of smaller dust particles. From the EDX spectrum of the sample, it was determined that the sample contains Oxygen 67.54%, Silicon

7.22%, Calcium 5.03%, Carbon 14.42%, Aluminum 2.76%, Iron 1.46%, Potassium 0.79% and Magnesium 0.79% by mass.

In powder sample 4, it was determined by comparing the peaks in the XRD spectrum with the peaks in the device library that the dominant mineral in the sample was quartz, but it also contained clay (Figure 4.b). The peaks of the clay mineral are more prominent in this sample compared to the other samples and indicate the smectite group.



(a) (b)

Figure 6.(a) SEM images and EDX spectrum of dust sample 4, (b) XRD spectrum of dust sample 4.

Dust deposition quantities for different dust samples

The results obtained from dust accumulation experiments are shown in Figure 7. The lowest dust accumulation was obtained in the experiments using the dust sample collected from location 2. When SEM analyses of this sample were examined, it was observed that the lowest dust size was observed in this sample.

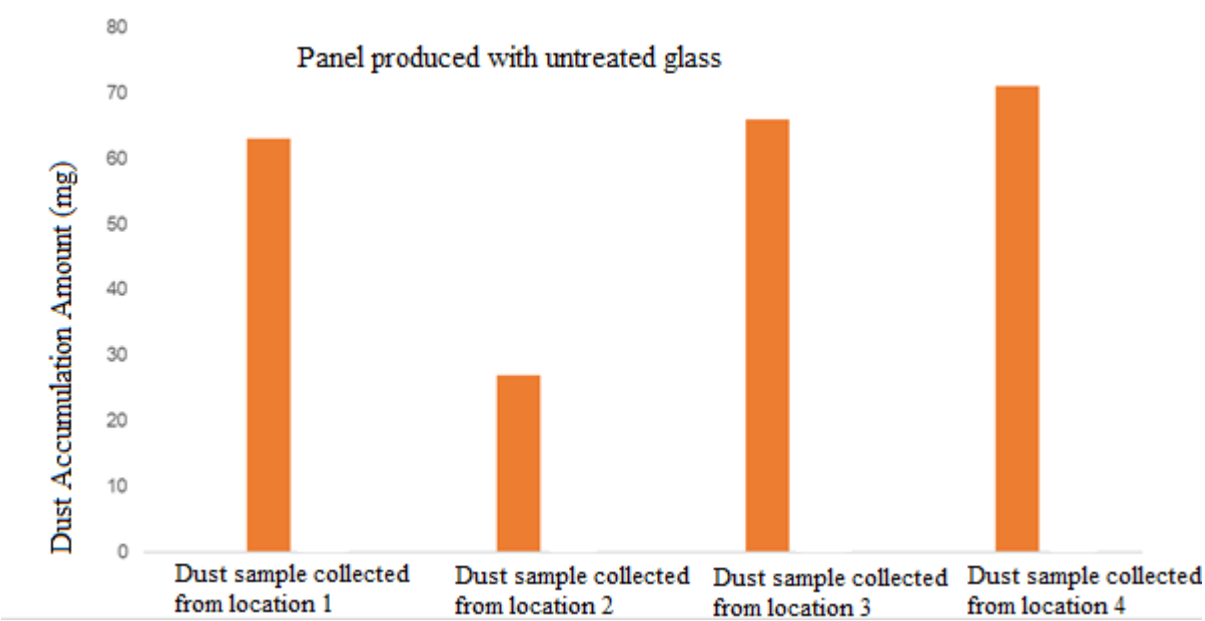


Figure 7. Dust accumulation amounts of the samples

The average particle size of the dust samples collected from location 2 was 3.804±1.74 µm. The average particle sizes of the dust samples collected from locations 1, 3 and 4 were 50.11±13.74 µm, 42.91±12.71 µm and 44.57±20.16 µm, respectively. This result shows that the longer air residence time of small sized dust particles is an effect that reduces the accumulation of dust on the panels.

The UV spectra of the experiments in which the light transmittances of the lamellas using different dust samples were analysed are shown in Figure 8.

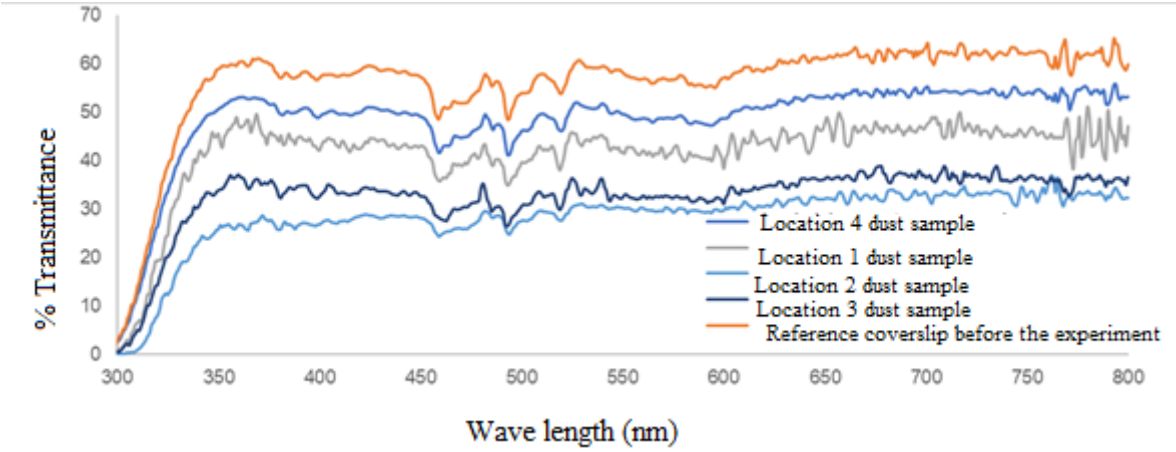


Figure 8. UV spectrum analysis.

Depending on the wavelength and angle of the light coming to a surface, a certain part of it passes through transparent objects, a certain part is absorbed by the substance and a certain part is reflected. In the experiments, a decrease in the amount of light passing through the physical phenomena mentioned above is expected in proportion to the dust accumulation on the surface. As can be seen from the figure 8, after the dusting experiment in which all dust samples were used, the % transmittance values of the lamellas at all wavelengths decreased. The lowest values were obtained in the dust sample collected from location 2.

It is surprising that the lowest light transmittance was obtained in the dust sample collected from location 2 where the lowest dust accumulation was observed. However, the fact that the dust size is much smaller in this sample compared to the other samples may be due to the fact that the surface reflects more light and therefore allows less light to pass through.

It shows that the size of the dust accumulated in PV panels also has a strong effect on yield losses. High yield loss results were obtained especially in dust samples collected from location 2, which has the lowest average size in dust samples with similar chemical and physical properties. In addition, the lowest yield losses were obtained in dust samples collected from location 1, which has the highest average particle size. Similar yield losses were obtained in dust samples collected from locations 3 and 4, where the particle size was very close to each other.

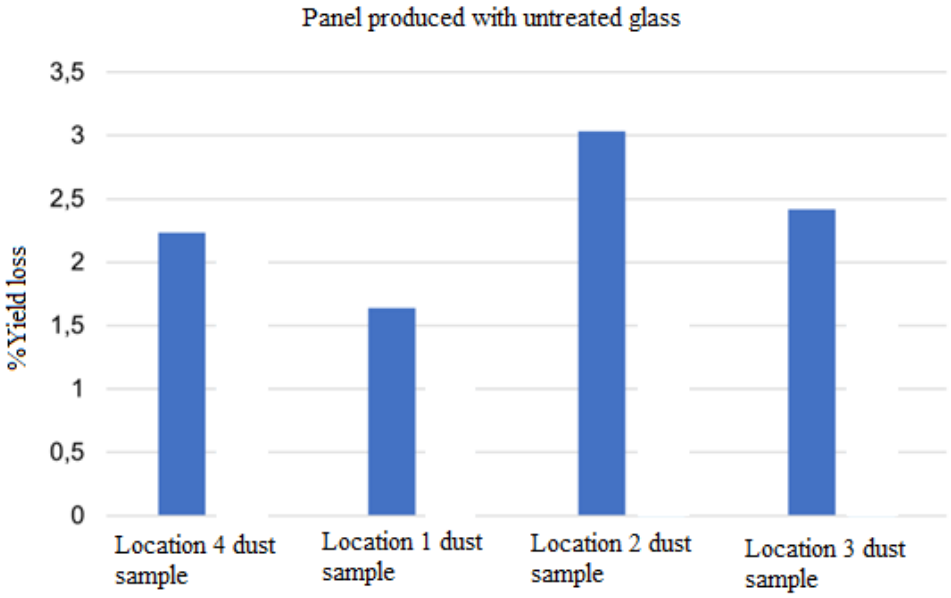


Figure 9. Yield losses obtained for different powder samples in sample panels

CONCLUSION AND RECOMMENDATIONS

The effect of the collected dust samples on the panel efficiency was investigated in the experimental setup. In the experimental setup, the amount of dust accumulation and efficiency losses on the sample panel, as well as the % transmittance changes of the sample lamellas were examined by controllable temperature, humidity, dust amount in the air and wind speed parameters in the laboratory environment. The results obtained revealed that the size of the dust has significant effects on efficiency losses and light transmittance beyond the amount of dust accumulation.

Thanks And Informatıon Note

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NUMERICAL ANALYSIS OF THE BEHAVIOR OF DIFFERENT ANODE MATERIALS IN LITHIUM-ION BATTERIES

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ABSTRACT

Nowadays, with the development of a clean environment understanding, being sensitive to the environment has become a sought-after feature in batteries. The sustainability and performance of lithium-ion batteries is also an important issue that is open to improvement. The most important issue affecting the performance of the battery is the components in the internal structure of the battery and the electrochemical working principle. The anode material called the negative electrode, which is one of the internal components of the battery, is very important in terms of battery performance. In this study, a numerical investigation of the behavioral properties of different negative electrode materials in lithium-ion batteries has been aimed. In line with this aim, four different anode materials which are Graphite1, Carbon, Carbon-based, and Graphite 2 are considered. Numerical analyses were performed by using the COMSOL application. The results bring out that the change of the anode material affects the performance of Li-ion batteries, and the best result of the simulated anode materials belongs to Graphite 2 material.

Keywords: Lithium-ion battery, Anode material, COMSOL.

Introduction

The energy demand has risen steadily in recent years as a result of fast technological advancements and long-term strategy. The increased consumption of fossil fuels, whose reserves are diminishing by the day, has exacerbated environmental issues such as global warming and air pollution, raising interest in cheaper, ecologically friendly, and safe renewable energy sources. One of the most important areas of renewable energy sources is energy storage. Since renewable energy resources are not continuous, energy storage is important in supplying the balance between energy supply and demand. The most efficient method for storing and reusing energy from renewable energy sources is battery-based storage systems. The most commonly used batteries in practice are lithium-ion batteries for modern electronic devices such as mobile phones and laptops due to their high energy density. Many metals react with lithium for high-capacity Li-ion battery applications. Rechargeable lithium-ion batteries, which have high specific energy, high energy storage capacity and a high number of cycles compared to their low size, have recently become an alternative energy source that has been studied with great care.

Lee et al. synthesized nitrogen doped graphene in microwave radiation with 8.1% nitrogen gas. Comparing the graphene sheet with nitrogen doping with undoped graphene, the electrical conductivity was significantly improved due to the change in electron mobility. At the same time, nitrogen atoms will provide more functional group designs for the material. The synergy between nitrogen-doped atoms also favorably affected the lithium storage performance of the material (Lee et al., 2014). Zhang et al. presented a large-scale, environmentally friendly way of producing graphene for used graphite anodes using a liquid-phase exfoliation approach aided by sonication. This method can potentially develop a high-value, highly efficient, and environmentally friendly recycling solution for used graphite (Zhang et al., 2017).

Ma et al. used microwave exfoliation and a spray-drying procedure to create rebuilt graphite with a carbon coating layer. When used in LIBs, the rebuilt graphite subsequently demonstrated improved specific capabilities and a lengthy cycle life (Z. Ma et al., 2018). Yan et al. processed bamboo leaves to create a layered carbonaceous material doped with nitrogen. When the bamboo leaves were acid-etched, the hydrated silica therein created porous structures. At a current density of 0.2 Ag^{-1}, the material maintains a capacity of 450 $mAhg^{-1}$ after 500 cycles, demonstrating strong lithium storage ability (Yan et al., 2020). One type of porous carbon nanomaterial is 3D graphene. Chemical reduction and hydrothermal processes are two of its large-scale manufacturing techniques that can produce nanomaterials with submicron pore diameters. Nevertheless, there are inherent flaws in the self-assembly process. There are a lot of flaws and layer connections in the constructed graphene network. Comparatively, the CVD technique works well for creating superior 3D graphene. (G. Li et al., 2019).

Through sulfur impregnation into activated N-doped hollow carbon nanofibers (ANHCNFs), Li et al. (Li et al., 2017) present a carbon-sulfur nanostructure with enhanced properties. This 50% sulfur material has a reversible capacity of 1230 mAh/g and sustains 920 mAh/g at 0.2C for 100 cycles. Using hydrothermal methods, Xiaoyu Dong et al. produced SiO_2/NGA nanocomposites, doped N-graphene aerogel. The produced composite shows a very large capacity of around 1052 mAh/g at 100 mA/g after 80 cycles, which is significantly higher than that of the graphite anode. The SiO_2/NGA composite's capacity to store lithium was first evaluated by examining the redox processes during the charge and discharge operation using a cyclic voltammetry (CV) curve (Dong et al., 2020). Ma et al. (Y. Ma et al., 2019) used a straightforward sol-static self-assembly approach to create the TNGC (TiO_2 nanorods homogeneously integrated on rGO) composite. The produced TNGC demonstrates a high cyclic stability of 353.6 mAh/g for LIBs anode after 100 cycles at 0.1 A/g. It also displays a decent rate capability of around 250.1 mAh/g at 2A/g. Due to its capacitive function in the charging/discharging process, plenty of active sites for electrochemical reactions, shortened Li+ diffusion path, wide surface area, and strong electrical conductivity, the TNGC composite is regarded as the best.

Materials and Methods

In the presented study, the working life and performance of the battery were investigated by changing the material of the anode component, known as the negative electrode in a Lithium-ion battery. While changing the material of the anode component, some properties are kept constant, and the properties of the anode materials are evaluated more readily and effectively. To investigate the performance of battery, numerical analyses as one dimensional were performed by using the COMSOL simulation code. The one-dimensional model is shown in Figure 1. Anode porous electrode, cathode porous electrode, separator, constant cathode materials, and electrolyte material were used as input to COMSOL application. Moreover, the component dimensions of the 1D battery are determined as $55x10^{-6}$m for the negative electrode part, $40x10^{-6}$m for the positive electrode part, and $30x10^{-6}$m for the separator part.

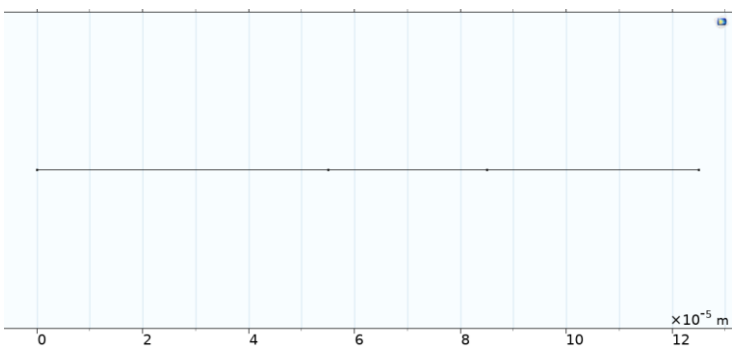


Figure 1. Li-ion battery 1D geometry

The anodes materials which are experimentally studied and tested in literature before were selected. The first material used is the anode material called Graphite1 (Ning et al., 2006). Graphite 1 is followed by Carbon (Shi et al., 2011), Carbon-based (Chabot et al., 2013), and Graphite 2 (Sharma et al., 2019), which are given various

names respectively. The operating temperature for all materials used is set as constant 298 K. The negative electrode is defined by entering the distinctive properties of the materials into COMSOL. When the heat capacity, density, reference concentration, and diffusion coefficient of the material attributes are modified, the battery's performance changes significantly. This study demonstrates how to simulate ageing at the negative electrode in a lithium-ion battery where a parasitic solid-electrolyte interface (SEI) formation reaction causes irreversible loss of convertible lithium.

It was assumed that each simulated charge-discharge cycle in the model represents an average aging behavior for a greater number of cycles T, and further assuming that all lithium captured in the SEI layer can be understood as originating from the negative electrode over the course of a single charge-discharge cycle, the capacity loss can be accelerated by adding the reaction formula to the stoichiometry of the SEI forming reaction;

$$(\tau-1)S+(\tau-1)Li(s)\rightarrow(\tau-1)P_{SEI}$$

To

$$S+Li^{+}+e^{-}\rightarrow P_{SEI}$$

resulting in

$$\tau S+Li^{+}+e^{-}+(\tau-1)Li(s)\rightarrow\tau P_{SEI}$$

here τ refers to seen as a time accelerating factor, representing how many real cycles each simulated battery cycle should depict. In this study, τ is set to 250.

Findings and Discussion

The numerical analyses were performed for different anode materials depending on different cycle numbers and working time. It was assumed that the battery discharged nine times for each analysis.

Figure 2 shows the variation of the cell voltage during discharge for different cycle numbers in each anode material. Subfigures consist of nine colored lines indicating each discharge number. As is apparent from this figure, in the case of anode material which is graphite 2 (Figure 2d), discharge curve number exceeding 3000 cycles is the highest. The first three discharges are over the 3000 cycles for graphite 2. In terms of battery discharge performance, this material is followed by carbon-based, graphite 1 and carbon materials. The material in Figure 2b in particular stayed at a low level.

The variation of relative capacity versus time is illustrated in Figure 3. Although there is a greater capacity fade rate during the initial cycles (plotted as blue line), both the capacity based on the total quantity of cyclable lithium and the nominal 1C discharge capacity (based on the time spent during the 1C discharge section of the load cycle) drop continually.

Figure 4 presents the local states of charge at the electrodes on the boundaries facing the separator. If the end-of-cycle evaluation is performed, the best result can be observed for Graphite 2 material (Figure 4d).

Conclusion

The expectation in lithium-ion batteries in which quite common is being extremely long of their service life. The aim of the studies in literature is to investigate the effect of the materials used in the components of the internal structure on this. For this purpose, the effect of different anode materials on the performance was examined numerically in the presented paper. Carbon-based anodes have been studied in this study and the best performance has been obtained in the material named Graphite 2, where carbon has a different structure.

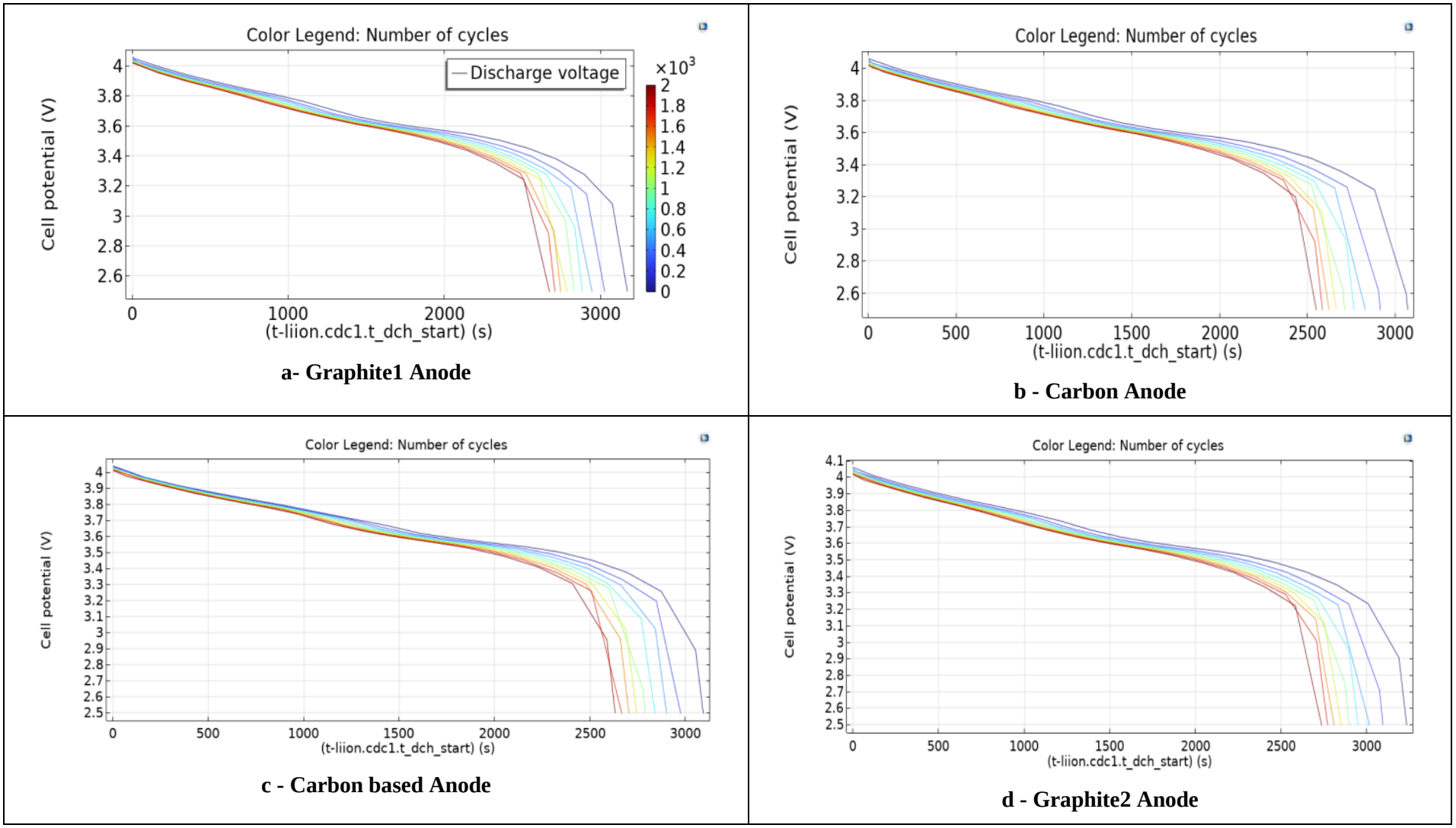
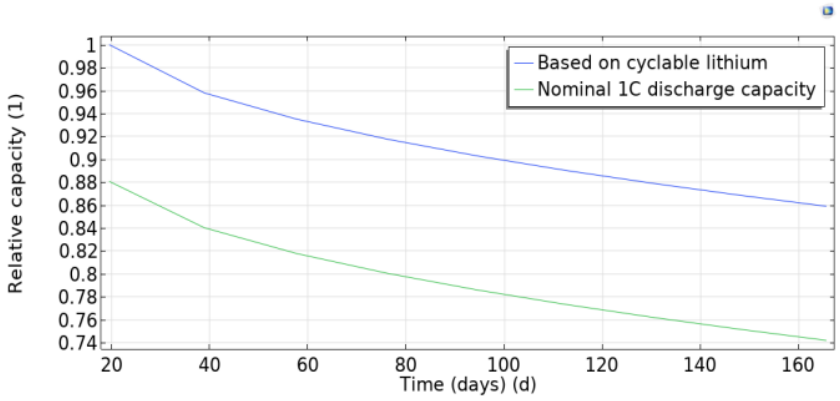
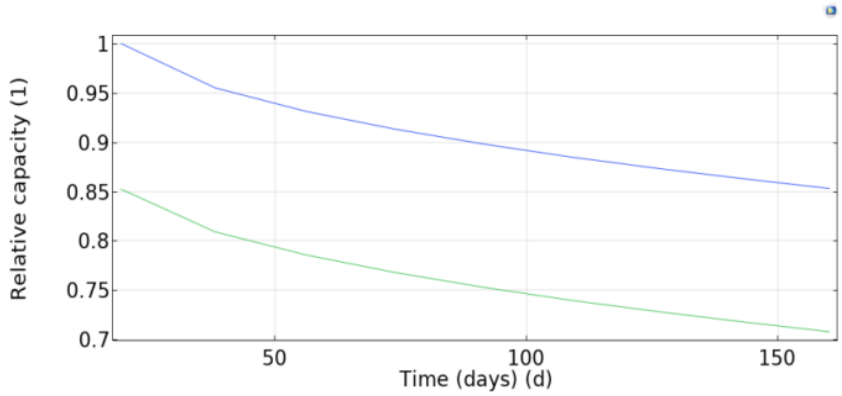


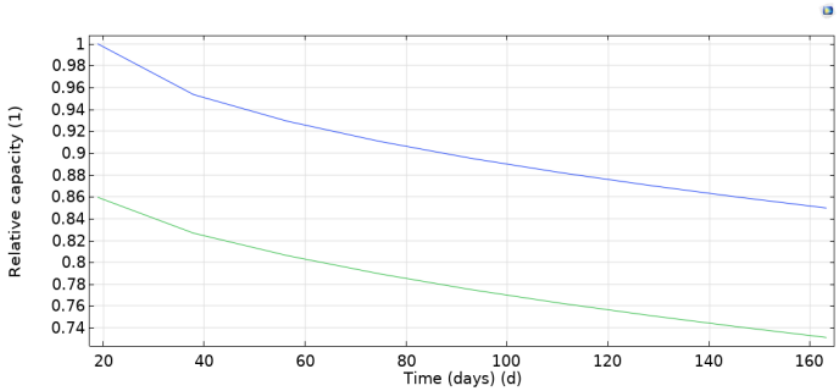
Figure 2. The variation of the cell voltage during discharge for different cycle numbers



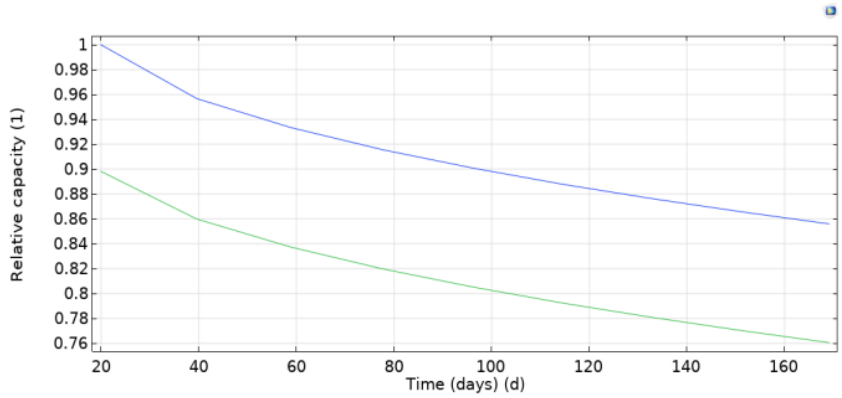
a- Graphite1 Anode



b - Carbon Anode

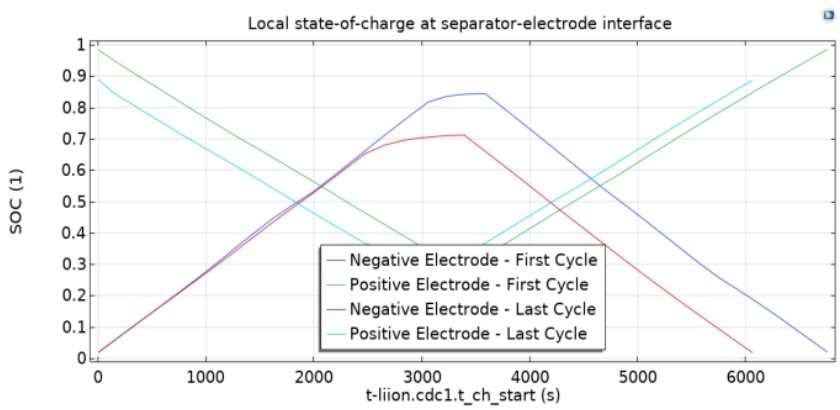


c - Carbon based Anode

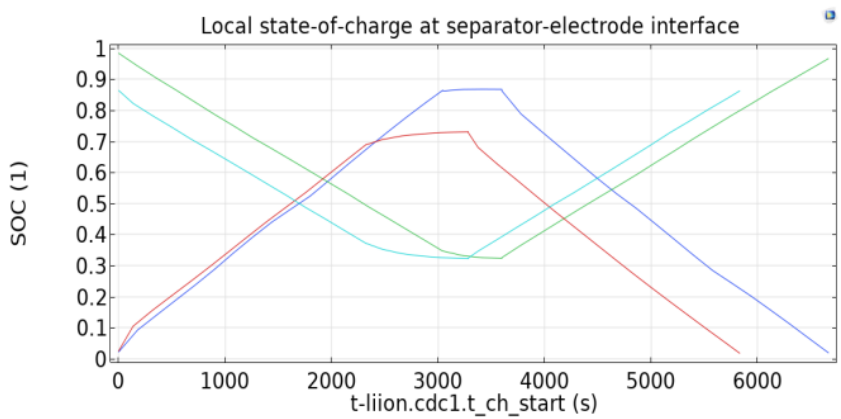


d - Graphite2 Anode

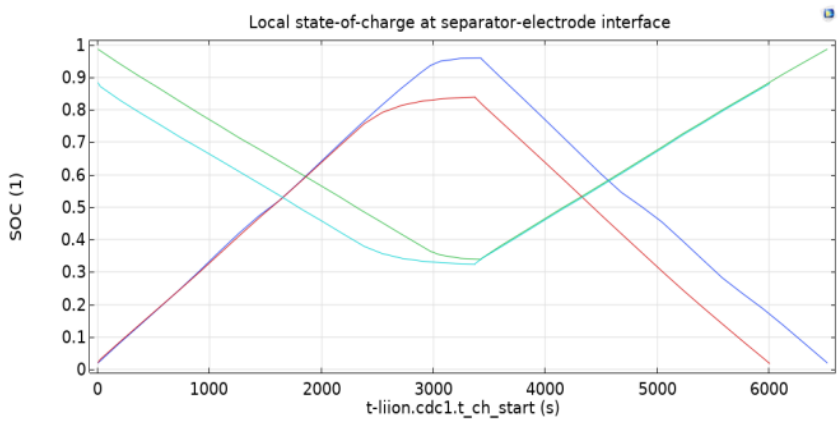
Figure 3. The variation of relative capacity versus time



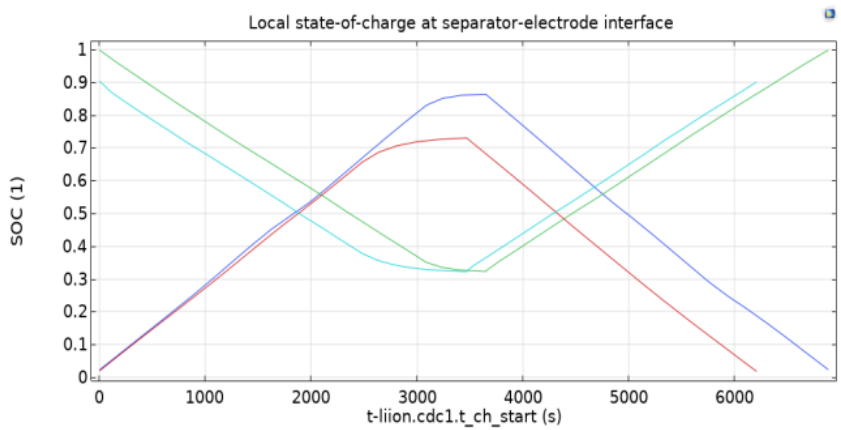
a- Graphite1 Anode



b - Carbon Anode



c - Carbon based Anode



d - Graphite2 Anode

Figure 4. Local states of charge at the electrodes on the boundaries facing the separator

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BENEFITS OF TEMPERATURE AND MIXING MODE VARIATIONS IN THE MONO- AND CO-DIGESTION ON THE SLUDGE LINE OF MUNICIPAL WWTPS

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ABSTRACT

The sewage sludge produced in municipal wastewater treatment plants (WWTPs) has reached millions of tons per year and requires high costs for its stabilization and proper disposal methods making 50-60% of the plant's operational costs. Anaerobic digestion of the sewage sludge is the best option for the stabilization and energy recovery in the form of methane and CO2 making up a major income for municipal WWTPs which are expected to expand in number and size worldwide. Primary sludge (PS) and secondary sludge (SS) (waste activated sludge), two sewage sludge fractions produced in municipal WWTPs having both primary sedimentation and biological treatment units, are mixed and co-digested conventionally but would inherit benefits in the separate mono-digestion system under different operational conditions as they possess different characteristics that could optimize the sludge line in terms of energy gain and stabilization degree.

In the present study, mono- and co-digestion models were implemented at two digestion temperature (DT) levels as 35 and 38°C and mixing modes as intermediate and continuous at organic loading rates (OLR) of 0.48-0.8, 0.28-0.33 and 0.39-0.58 kg VS/m^3.d for PS, SS and mixed sludge (MS), respectively. Increasing degree of mixing mode was more influential on the methane yield as specific methane production (SMP) at 93% increase than DT rise which provided an increase at 11% in PS digestion. Contrarily, low level of mixing degree gave 26% more SMP in SS digestion with only 4% increase with DT rise. A 12% increase in low degree mixing and DT rise was effective in co-digestion (MS). Optimum operational conditions for PS and SS were CM+35°C and IM+35°C, respectively, at low OLRs resulting 38% and 97% higher OLR and daily methane production, respectively, compared to co-digestion at IM+38°C as the optimum operational condition which required a higher degree of energy input for the stabilization process. The study showed a high potential of parallel mono-digestion system in terms of energy recovery and savings in municipal WWTPs towards efficiency improvement on the conventional system with a feasible modification.

Keywords: Sewage sludge, anaerobic digestion, energy, recovery, operation..

Introduction

Anaerobic digestion is the best option for the stabilization and energy recovery from sewage sludge produced in municipal wastewater treatment plants (WWTPs) reaching millions of tons per year requiring high costs for its stabilization and proper disposal methods making 50-60% of the overall plant's operational costs (EPA, 2008). Biogas obtained in the form of methane and CO_2 makes up a major income for municipal WWTPs which are expected to expand in number and size worldwide (Mininni et al., 2015).. The existing sludge line tools have potential for amelioration in biogas increase and sludge volume reduction as dry solid (DS) content increases. Primary sludge (PS) and secondary sludge (SS) (waste activated sludge), two sewage sludge fractions produced in municipal WWTPs having both primary sedimentation and biological treatment units, are mixed, thickened and co-digested conventionally (Tchobanoglous et al., 2003). Potential benefits in the separate mono-digestion system under different operational conditions need to be investigated as PS and SS possess different characteristics that could optimize the sludge line in terms of energy gain and stabilization degree. The low volatile solid (VS) (%0.8-0.9DS) content of the SS is resistent even to anerobic biodegradation and the result is a 40-45% stabilized mixed sludge with high water content. The SS flow is usually at an equal rate to PS which gets diluted from 3.5-4.0%dry solids (DS) down to 2.0-2.5%DS and a 3.5-3.8%DS is the final thickened degree which

In the present study, mono- and co-digestion models were implemented at two digestion temperature (DT) levels as 35 and 38°C and mixing modes as intermediate and continuous at organic loading rates (OLR) of

0.48-0.8, 0.28-0.33 and 0.39-0.58 kg VS/m3.d for PS, SS and mixed sludge (MS), respectively. Increasing degree of mixing mode was more influential on the methane yield as specific methane production (SMP) at 93% increase than DT rise which provided an increase at 11% in PS digestion. Contrarily, low level of mixing degree gave 26% more SMP in SS digestion with only 4% increase with DT rise. A 12% increase in low degree mixing and DT rise was effective in co-digestion (MS). Optimum operational conditions for PS and SS were CM+35°C and IM+35°C, respectively, at low OLRs resulting 38% and 97% higher OLR and daily methane production, respectively, compared to co-digestion at IM+38°C as the optimum operational condition which required a higher degree of energy input for the stabilization process. The study showed a high potential of parallel mono-digestion system in terms of energy recovery and savings in municipal WWTPs towards efficiency improvement on the conventional system with a feasible modification. (Tol, 2002).

Materials and Methods

Mono- and co-digestion models were implemented for PS and SS with parallel lab-scale anaerobic semi continuous reactors. The reactors had active volumes of 1800 mL. The inoculum sludge was provided from the WWTP's anaerobic digester. Two digestion temperature (DT) levels as 35 and 38°C and mixing modes as intermediate (IM) and continuous mixing (CM) were applied in two sequential periods. CM mode was applied in a water bath placed on top of magnetic stirrers. Organic loading rates (OLR) were 0.48-0.8 kg VS/m^3.d for PS, 0.28-0.33 kg VS/m^3.d for SS, and 0.39-0.58 kg VS/m^3.d mixed sludge (MS) digestion. The feeding and sludge wasting was conducted in a daily basis. Hydraulic retention time (HRT) was kept constant at 20 d. Daily methane production was measured by liquid displacement method. Volatile solids (VS) were analyzed using standart methods (2540 B ve E) (APHA, 2005). Each period of the study was conducted for 55-60 d periods for each OLR.

Findings and Discussion

Waste stabilized sewage sludge produced was 147 ton/d for a flow rate 147 000 m^3/d for the real scale WWTP. Daily methane production obtained in the PS digesters was presented in the Figure 1. Increase in DT did not produce a significant effect in the intermittent mixing mode. Increase in DT produced a significant effect in the continuous mixing mode. Increasing degree of mixing mode was more influential on the biomethanation as methane production increased more than DT rise in PS digestion. Increasing degree of mixing mode was more influential on the methane production as 93% increase than DT rise which provided an increase at 11% in PS digestion. Results in SS digestion were opposite to PS digestion (Figure 2). Intermediate mixing mode gave 20-30% more SMP with only 4% increase with DT rise. Daily methane production is 3 times higher and spesific methane yield was 1.3 times higher in PS digestion than SS digestion (Figure 3).

The trend in MS digestion was similar to SS digestion (Figure 4 a-b). Intermittent mixing produced a higher methane production. The mixing of PS increased biomethanation of SS digestion.

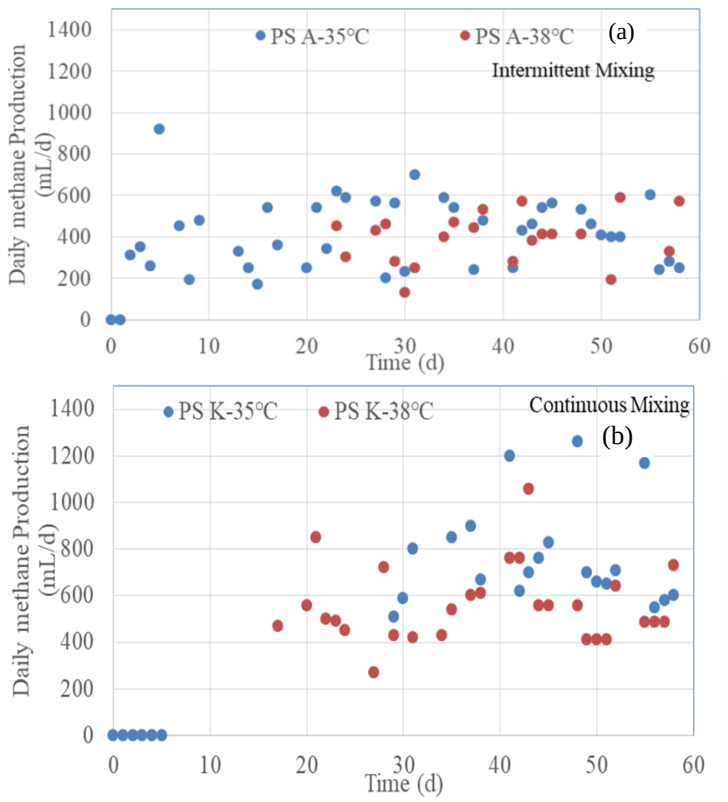

Figure 1. Daily methane production in PS digesters (a) IM and (b) CM

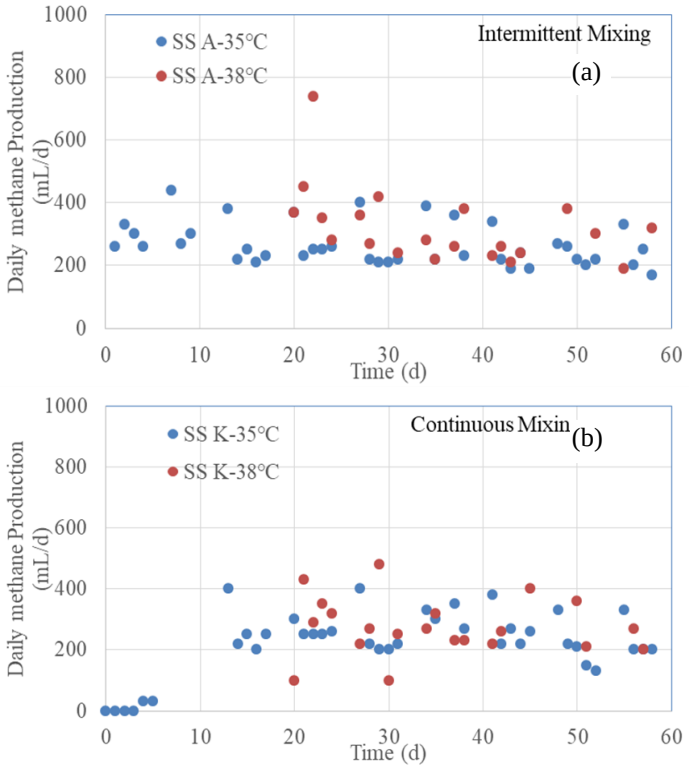

Figure 2. Daily methane production in SS digesters (a) IM and (b) CM

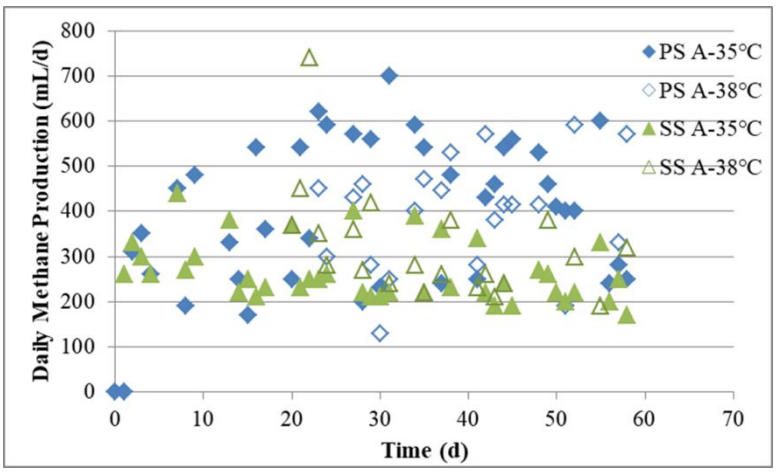

Figure 3. Comparative methane production in PS and SS digesters in IM mode

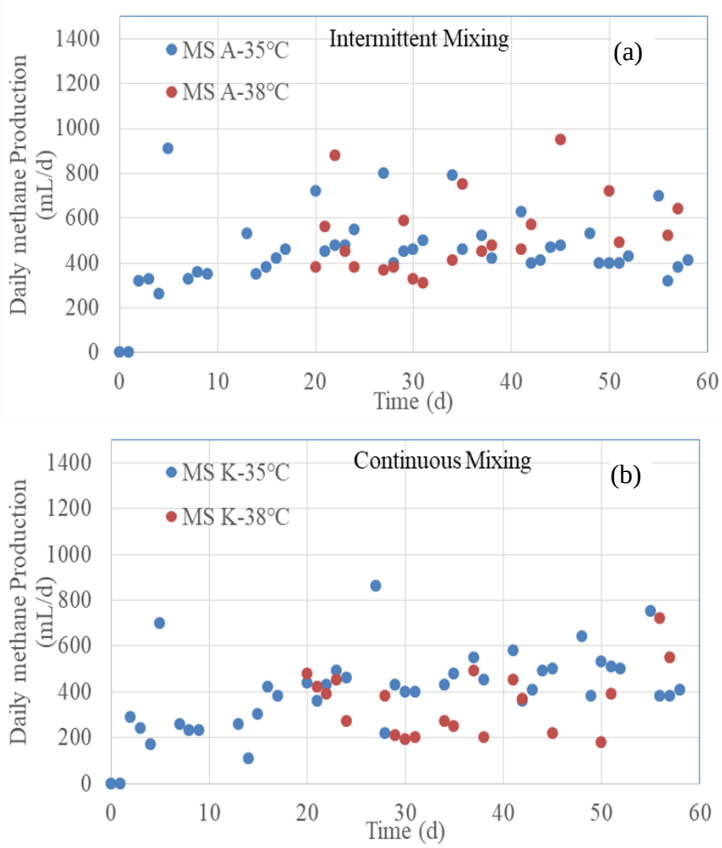

Figure 4. Comparative methane production in MS digesters in (a) IM and (b) CM mode

Conclusion and Recommendations

The optimum operational conditions were continuous mixing+35°C for PS digestion and intermediate mixing+35°C for SS digestion whereas intermediate mixing+38°C resulted better for MS digestion. Co-digestion required a DT increase and intermittent mixing mode for the highest methane production. Intermittent mixing produced a higher methane production in SS and MS digestion. Continuous mixing increased methane production to a significant level but DT rise reduced it as a sign of inhibitory effect of the intermediate products on the biomethanation of PS. Mono-digestion showed potentials as: co-digestion requiring a DT rise to reach the methane produced in the mono-digestion of PS and SS at 35°C, an increase in efficiency can be reached with partial mixing of PS into SS digester either at 35 or 38°C, 38% and 97% higher OLR was enabled compared to co-digestion at IM+38°C, the optimum operational condition for co-digestion required a higher degree of energy input for the stabilization process at IM+38°C.

Thanks and Information Note

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A COMPARATIVE ANALYSIS OF WASTE DISPOSAL METHODS AND METHODOLOGIES ABOUT GREENHOUSE GAS EMISSIONS FOR ACHIEVING A SUSTAINABLE FUTURE

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ABSTRACT

The quantification of greenhouse gas emissions is crucial in addressing global climate change, forming the basis for efforts to attain a sustainable future. The significance of greenhouse gas emissions generated by solid waste cannot be disregarded. The measurement of emissions associated with waste materials depends on elements such as the properties of the waste, the method of disposal, and the calculating methodology employed. Effectively managing waste is crucial for minimizing environmental impacts and promoting the shift towards a circular economy by encouraging sustainable use of resources. This study utilized the Waste Reduction technique developed by the United States Environmental Protection Agency to examine greenhouse gas emissions resulting from solid waste based on the chosen waste management approach. This methodology is an invaluable instrument for quantifying the environmental advantages linked to waste reduction and recycling endeavors from a life cycle standpoint. Based on the acquired results, it was recommended to prioritize the recycling method due to its low greenhouse gas emissions. The efficacy of combusting techniques varied based on the attributes of the solid waste and did not ensure a decrease in greenhouse gas emissions in every instance. The utilization of combusting, composting, and anaerobic digesting techniques for treating organic waste has resulted in a decrease in emissions as compared to the landfill method. Consequently, it has been discovered that the selection of waste disposal methods plays a crucial role in addressing climate change and emphasizes the significance of carefully choosing waste disposal techniques to minimize greenhouse gas emissions.

Keywords: Solid waste, disposal methods, EPA WARM, GHG Emissions, Climate Change

INTRODUCTION

The measurement of greenhouse gas emissions (GHGs) resulting from various waste management practices is a crucial element of maintaining environmental sustainability and mitigating climate change. Several studies have focused on the significance of assessing and contrasting the GHGs linked to diverse waste management methods in order to comprehend their environmental consequences and steer decision-making towards more sustainable alternatives. As an example, Zhao et al. (2011) performed a case study in Tianjin, China, to evaluate the eco-efficiency of municipal solid waste management in reducing GHGs (Zhao et al., 2011). The research emphasized the growing quantities of municipal solid waste and the constrained capabilities of waste treatment facilities in China, underscoring the necessity to tackle the environmental consequences of waste management. In a similar vein, Martin & Danielsson (2016) conducted a study on the European Union, employing a life cycle methodology to assess the environmental impact of various policies related to protein intake reduction, food waste management, and donations(Martin & Danielsson, 2016). Their research highlights the significant environmental consequences of dynamic policies on food consumption and waste management. Gallo et al. (2020) examined different waste management options in the maritime industry from the perspective of a circular carbon economy (Gallo et al., 2020). They emphasized the importance of categorizing waste into various types, including oil-ballast water, black water, grey water, solid waste, and hazardous waste. The researchers highlighted how sustainable waste management plays a crucial role in reducing greenhouse gas emissions. Barrera and Hooda (2016) conducted a case study analyzing the GHGs associated with waste management processes (de la Barrera & Hooda, 2016). The study provided detailed data on emissions from various waste management scenarios, contributing to a better understanding of the environmental consequences of different waste management options. These studies collectively show the importance of assessing and comparing the GHGs of various waste management methods. Evaluating GHGs is essential for identifying environmentally sustainable strategies, comprehending their influence on climate change,

informing policy and regulatory frameworks, and advocating for sustainable waste management worldwide (Kwon et al., 2018; Woldu et al., 2019). Hence, the objective of this study was to perform a comprehensive analysis using the Environmental Protection Agency Waste Reduction Model (EPA WARM) model in order to uncover the variations in GHGs based on the method of waste disposal (US EPA, 2023). The EPA WARM has been utilized in the literature. Mohareb et al. (2011) compared various waste emissions quantification methods, including the EPA WARM, to evaluate their effectiveness (Mohareb et al., 2011). Additionally, Deus et al. (2017) highlighted the widespread use of the EPA WARM for determining optimal strategies to reduce greenhouse gas emissions and energy consumption in household solid waste management scenarios (Deus et al., 2017).

Assessing and contrasting the levels of GHGs from various waste management methods is of utmost importance for several reasons. First and foremost, it enables the identification of the most ecologically sustainable waste management strategies. This comparison is crucial for assessing waste management practices that yield reduced greenhouse gas emissions, thereby directing decision-makers towards more ecologically sustainable alternatives. Research has shown that waste management activities play a crucial role in the generation of greenhouse gas emissions, specifically by releasing methane and carbon dioxide (Chen, 2018; Weitz et al., 2002). Through the assessment of these emissions, it is feasible to measure the environmental consequences of various waste management methods and devise tactics to reduce their impact on climate change. Moreover, the assessment and juxtaposition of GHGs resulting from waste management practices are crucial in providing information for policy and regulatory frameworks. Gaining insight into the ecological consequences of different waste management alternatives is crucial for formulating efficient regulations and standards with the objective of mitigating greenhouse gas emissions. Technological advancements and environmental regulations have played a crucial role in reducing the environmental effects of waste management, such as greenhouse gas emissions. This is especially important in the field of municipal solid waste management (Yedla & Sindhu, 2016). Estimating and comparing GHGs of various waste management practices is crucial for determining environmentally sustainable strategies, comprehending their effects on climate change, informing policy and regulatory frameworks, and promoting global sustainable waste management. The objective of this study was to perform a comprehensive analysis using the Environmental Protection Agency Waste Reduction Model (EPA WARM) in order to uncover the variations in GHGs based on the method of waste disposal. This study makes a valuable contribution to the existing literature by using the EPA WARM model and addressing waste management models.

MATERIALS AND METHODS

The Environmental Protection Agency Waste Reduction (EPA WARM) Model

The EPA WARM is a tool that calculates the possible GHG emissions, energy savings, and economic effects of several waste management strategies (US EPA, 2023). These methods include source reduction, recycling, burning, composting, anaerobic digestion, and landfilling. The model quantifies emissions, energy units, and economic considerations for various material types usually included in municipal solid trash, encompassing a diverse variety of categories, such as Metric tons of carbon dioxide equivalent ($MTCO_2e$). Using a life cycle viewpoint, the EPA WARM methodologhy can quantify GHGs for a selection of materials. It can perform calculations for the many waste disposal methods, including recycling, landfill, combusting, composting, and anaerobically digesting (Lee et al., 2016).

This study utilized the EPA WARM Model as the assessment methodology for quantifying greenhouse gas emissions. In order to evaluate the GHG emissions of solid waste, two distinct material groups were selected as the scenarios.

Scenarios

Two separate scenarios were assessed within the scope of this study. Table 1 presents the materials and waste management methods employed in scenario 1. This scenario involved options for recycling, landfilling, and combustion, specifically designed for eight separate materials categorized into five different classifications.

Table 1. Materials Types for Scenario 1

No	Material Type	Material	Landfill	Recycling	Combusting
1	Glass	Glass	✓	✓	✓
2	Metal	Steel cans	✓	✓	✓
3	Metal	Aluminium cans and foil	✓	✓	✓
4	Paper	Office paper	✓	✓	✓
5	Plastic	HDPE	✓	✓	✓
6	Plastic	PET	✓	✓	✓
7	Plastic	PP	✓	✓	✓
8	Electrical items	Mixed Electronics	✓	✓	✓

The second scenario was designed specifically for one type of material including three materials. Scenario 2's materials and waste management methods are listed in Table 2. The waste management options considered in this scenario for three organic materials included landfilling, combusting, composting, and anaerobic digestion.

Table 2. Materials Types for Scenario 2

No	Material Type	Material	Landfill	Combusting	Composting	Anaerobic digestion
1	Organic	Grass	✓	✓	✓	✓
2	Organic	Leaves	✓	✓	✓	✓
3	Organic	Food Waste	✓	✓	✓	✓

To facilitate comprehension of calculations and variations, waste quantities are standardized to 1 ton for all materials. Landfill is the accumulation of waste materials in a designated place for storage. Recycling is the act of transforming wasted materials into new goods to avoid waste and preserve resources. Combustion refers to the deliberate burning of waste materials in a controlled manner to produce energy. Composting refers to the process of organic matter breaking down naturally into soil rich in nutrients, thanks to the action of microorganisms. Anaerobic digestion refers to the decomposition of organic waste through the activity of microorganisms in an oxygen-free environment (Kan, 2009). This process results in the production of biogas and byproducts that are rich in nutrients.

FINDINGS AND DISCUSSION

Calculations for selected material groups were performed using the EPA WARM model. Results were obtained for 11 materials in 6 groups. The GHG Emissions of the materials in the first scenario is given in Table 3. According to the results, the combusting method is the worst method according to the GHG emissons except Steel cans and Office paper mateiral. The highest effect was observed in the landfill method with 1.13 Metric CO_2E equvalent for office paper. Remaning materials had lower impact for landfill method. The best method with lowest GHG Emissons was the recycling. With recycling the Aluminium cans and foil the highest contribution was provided. Because THE EPA method had life cycle perspective, recycling of Aluminium cans and foil contributed the saving of -9.13 Metric CO_2E for per ton. Recycing method's contribution was the lowest in glass material. Combusting method had lower impact than landfill for only in Steel cans and Office paper.

The EPA WARM model was utilized to conduct calculations for specific material categories. Results was obtained for a total of 11 items, which were divided into 6 distinct groups. The GHG emissions of the materials in the first scenario are provided in Table 3. Based on the findings, the combusting method exhibits the highest

GHG emissions, except for steel cans and office paper material. The landfill approach exhibited the most significant impact, with a measurement of 1.13 metric CO_2 equivalent (E) for office paper. The remaining materials had a reduced environmental impact when disposed of in a landfill. Recycling was the most effective approach with the least amount of GHG emissions. The biggest contribution was made through the recycling of aluminum cans and foil. Because of the life cycle viewpoint of the EPA technique, the recycling of aluminum cans and foil resulted in a reduction of -9.13 metric CO_2E per ton. The recycling procedure had the least impact on the glass material. The combustion process had a lower environmental impact compared to landfilling, but only for steel cans and office paper.

Table 3. The GHG Emissions of the materials in Scenario 1 (Unit: Metric CO_2E)

Material Type	Material	Landfill	Recycling	Combusting
Glass	Glass	0.02	-0.28	0.03
Metal	Steel cans	0.02	-1.83	-1.59
Metal	Aluminium cans and foil	0.02	-9.13	0.03
Paper	Office paper	1.13	-2.86	-0.47
Plastic	HDPE	0.02	-0.76	1.29
Plastic	PET	0.02	-1.04	1.24
Plastic	PP	0.02	-0.79	1.29
Electrical items	Mixed Electronics	0.02	-0.79	0.39

The change ratio in greenhouse gas emissions of alternative strategies was calculated relative to landfills, which is the predominant method for managing solid waste. The improvement ratios based on the reference technique are identified in Table 4. The landfill was used as a reference method. Negative values indicate a decrease in greenhouse gas emissions. When Recycling was used as the disposal method, it resulted in a significant decrease of 45163% in the aluminum can and foil product. The paper product had the lowest performance, with only a 353% improvement. Consequently, the recycling method effectively reduced greenhouse gas emissions in all materials. Office paper exhibited the smallest increase in improvement, with a rate of 142%, whereas steel cans showed the highest improvement ratio of 7955% as a result of the transition to the combustion process. When compared to landfill disposal, all leftover materials exhibited elevated levels of greenhouse gas emissions. Note that these results were obtained using the life cycle approach of the EPA WARM model. Instead of exclusively displaying the values generated by waste management, the life cycle perspective takes into account the entirety of the product's life cycle.

Table 4. Improvement Ratio of the methods in Scenario 1 (*Reference Scenario, Unit: %)

Material Type	Material	Landfill*	Recycling	Combusting
Glass	Glass	0	-1463	33
Metal	Steel cans	0	-9145	-7955
Metal	Aluminium cans and foil	0	-45163	70
Paper	Office paper	0	-353	-142
Plastic	HDPE	0	-3845	6249
Plastic	PET	0	-5214	6030
Plastic	PP	0	-4019	6263
Electrical items	Mixed Electronics	0	-3977	1810

The greenhouse gas emissions of the materials in scenario 2 are presented in Table 5. The landfill method generated the most significant results for grass and food waste. The third biggest impact was attributed to grass in anaerobic digestion. Regarding leaves, every substitution method resulted in the reduction of GHG, with composting having the highest impact among them. Combusting yields the highest reduction in GHG emissions among these three materials.

Table 5. The GHG Emissions of the materials in Scenario 2 (Unit: Metric CO_2E)

Material Type	Material	Landfill	Combusting	Composting	Anaerobic digestion
Organic	Grass	0.116	-0.167	-0.054	0.005
Organic	Leaves	-0.534	-0.167	-0.054	-0.142
Organic	Food Waste	0.497	-0.134	-0.116	-0.042

The improvement ratios, as per the reference technique, are provided in Table 6. Food waste GHG emissions were significantly decreased by 216% by combustion, while there was a 69% decrease in leaves and a notable 244% decrease in grass. Consequently, all alternative waste management options exhibit lower GHG emissions than landfills for these materials.

Table 6. Improvement Ratio of the methods in Scenario 2 (*Reference Scenario, Unit: %)

Material Type	Material	Landfill*	Combusting	Composting	Anaerobic digestion
Organic	Grass	0	-244	-146	-96
Organic	Leaves	0	-69	-90	-73
Organic	Food Waste	0	-216	-200	-136

CONCLUSION AND RECOMMENDATIONS

In this study, two scenarios were created based on the waste disposal method. The study examined the GHG emissions for 11 product groupings in both scenarios, using the EPA WARM methodology. The second step of the study focused on examining the variation in GHG emissions resulting from alternate waste disposal strategies, as compared to landfilling, which is the most commonly employed method.

The findings indicate that the selection of the waste disposal strategy is significant in terms of comes to tackling climate change. Hence, when aiming to decrease greenhouse gas emissions, it is crucial to meticulously select the waste disposal technique and regulate the quantity of waste generated. Based on the EPA WARM model, which adopts a life cycle approach, the recycling method should be prioritized since it results in the lowest GHG emissions. The impact of the combustion methods varied based on the characteristics of the solid waste and did not guarantee the reduction of GHG emissions in all cases. Regarding organic waste in Scenario 2, the methods of combustion, composting, and anaerobic digestion all resulted in an emission decrease when compared to disposal.

Further studies could involve examining the outcomes under various real-world situations and employing diverse waste management methodologies and GHG protocols. This study guides decision-makers in developing waste management models.

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ANAEROBIC DIGESTION CHARACTERISTICS OF PRIMARY AND SECONDARY SEWAGE SLUDGES AT LOW ORGANIC LOADING RATES AT THE UPPER MESOPHILIC LEVEL

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ABSTRACT

The sewage sludge produced in municipal wastewater treatment plants (WWTPs) as primary sludge (PS) and secondary sludge (SS) (waste activated sludge) fractions in primary sedimentation and biological treatment units, respectively, have different characteristics in terms of anaerobic digestibility that need to be investigated under different operational conditions. As a significant pollutant in volume and impact sewage sludge needs improving in stabilization and disposal methods to reduce its share at 50-60% of the plant's operational costs. Anaerobic digestion of the sewage sludge is widely implemented as the best option for the stabilization and energy recovery in the form of methane making up a major income for municipal WWTPs which are expected to increase in number and size worldwide. In the present study, mono- and co-digestion models were implemented and evaluated comparatively at two digestion temperature (DT) levels as 35 and 40°C (upper mesophilic level), and mixing modes as intermediate mode (IM) and continuous mode (CM) at relatively low organic loading rates (OLR) of 0.48-0.8, 0.28-0.33 and 0.39-0.58 kg VS/m^3.d for PS, SS, and mixed sludge (MS), respectively. Upper mesophilic temperature had positive and negative impact depending on the mixing mode on the methane production in PS digestion in comparison to 35°C whereas negative impacts reduced biomethanation in SS digestion. The highest methane production conditions were obtained as IM for SS digestion, CM for PS, IM mode for MS digestion at 35°C. Volatile solid (VS) reduction increased while methanogenic activity dropped pointing out to fastened hydrolysis reaction and the negative effect of the intermediate products on methanogenic activity. pH drop in PS digestion showed that carbohydrates and lipids were degraded mostly indicating increased acidogenic and decreased methanogenic activity while proteinaceous matter was degraded in SS digestion. Reduced methane production at the same OLR while VS increased pointed out to increased biosynthesis in the IM mode supported by the reduced electrical conductivity. Co-digestion at the upper mesophilic level improved biomethanation lowered in the CM mode is SS digestion.

Keywords: Sewage sludge, anaerobic digestion, energy, recovery, upper mesophilic temperature.

Introduction

The sewage sludge produced in municipal wastewater treatment plants (WWTPs) as primary sludge (PS) and secondary sludge (SS) (waste activated sludge) fractions in primary sedimentation and biological treatment units, respectively, have different characteristics in terms of anaerobic digestibility that need to be investigated under different operational conditions. As a significant pollutant in volume and impact sewage sludge needs improving in stabilization and disposal methods to reduce its share at 50-60% of the plant's operational costs (EPA, 2008). Anaerobic digestion of the sewage sludge is widely implemented as the best option for the stabilization and energy recovery in the form of methane making up a major income for municipal WWTPs which are expected to increase in number and size worldwide (Mininni et al., 2015). The conventional parameters are 35-37°C of digestion temperature (DT) for mesophilic range, 55-60°C for thermophilic level, continuous mixing, and 18-25 d of hydraulic retention time (HRT)(Tchobanoglous et al., 2003). The existing sludge line tools have potential for amelioration in biogas increase and sludge volume reduction as dry solid (DS) content increases. PS and SS are mixed, thickened and co-digested conventionally in municipal WWTPs. Potential benefits in the separate mono-digestion system under different operational conditions need to be investigated as PS and SS possess different characteristics that could optimize the sludge line in terms of energy gain and stabilization degree. The low volatile solid (VS) (%0.8-0.9DS) content of the SS is resistent even to anerobic biodegradation and the result is a 40-45% stabilized mixed sludge with high water content. The SS flow is usually at an equal rate to PS which gets diluted from 3.5-4.0%dry solids (DS) down to 2.0-

2.5%DS and a 3.5-3.8%DS is the final thickened degree whish is expected to reach 5% for a good-level anaerobic digester feding.

In the present study, mono- and co-digestion models were implemented at two digestion temperature (DT) levels as 35 and 40°C and mixing modes as intermediate mixing (IM) and continuous mixing (CM) at relatively low organic loading rates (OLR) for PS, SS and mixed sludge (MS) compared to real scale applications. The effect of digestion and mixing modes and temperature increase were monitored and evaluated on the methane production, VS concentration, pH and electrical conductivity (EC) for each sludge digestion model.

Materials and Methods

Mono- and co-digestion models were implemented for PS and SS with parallel lab-scale anaerobic semi continuous reactors. The reactors had active volumes of 1500 mL. The inoculum sludge was provided from the WWTP's anaerobic digester. Two digestion temperature (DT) levels as 35 and 40°C were applied in two sequential periods with mixing modes as intermediate (IM) and continuous mixing (CM). CM mode was applied in a water bath placed on top of magnetic stirrers. Organic loading rates (OLR) were 0.48-0.8 kg VS/m^3.d for PS, 0.28-0.33 kg VS/m^3.d for SS, and 0.39-0.58 kg VS/m^3.d mixed sludge (MS) digestion. The feeding and sludge wasting was conducted in a daily basis. Hydraulic retention time (HRT) was kept constant at 20 d. Daily methane production was measured by liquid displacement method. Volatile solids (VS) were analyzed using standart methods (2540 B ve E) (APHA, 2005). pH and EC were determined using Hach Lange Multi Parameter and WTW conductivity meter, respectively. Each period of the study was conducted for 55-60 d periods for each OLR.

Findings and Discussion

The highest methane production was obtained 824 mL/d at 35°C and CM in the PS digestion (Figure 1 a-b). Increase in DT produced reverse results on the biomethanation as a positive effect in the IM mode and a negative effect in the CM mode. Increase in DT produced a negative effect in the CM mode which indicated enhanced hydrolysis and inhibition by the elevated intermediate products. Mixing mode was more efficient on the biomethanation as it was doubled from IM to CM mode at 35°C whereas DT rise resulted in a 28% increase in the IM mode.

Upper mesophilic level reduced methane production in the SS digestion at both mixing levels (Figure 2 a-b). IM mode was more effective on the biomethanation as 265 mL CH_4/d was the highest rate obtained at 35°C. Similarly for MS digestion the IM mode and 35°C were the optimum operational conditions giving the highest daily methanation rate at 471 mL/d. DT rise to 40°C reduced methanogenic activity.

The ratio of methane produced in PS digestion to SS digestion ranged at 1.54-3.22 depending on the operational conditions. The ratio for PS over MS digestion occurred at 0.87-1.96

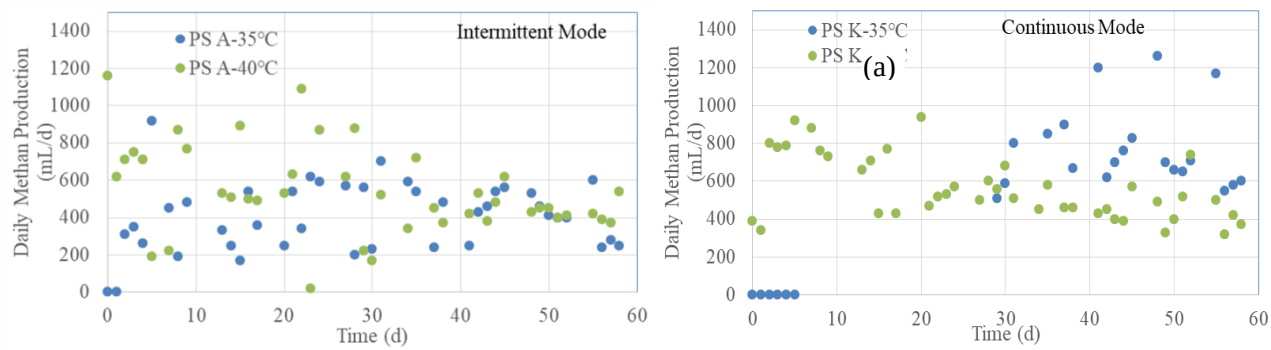

Figure 1. Daily methane production in PS digesters

indicating that under some operational conditions co-digestion improved single biomethanation patterns. The variation was high in PS digestion with a (+/-)176 mL/d standard deviation compared to 32 and 23 (+/-)176 mL/d for SS and MS digestion, respectively.

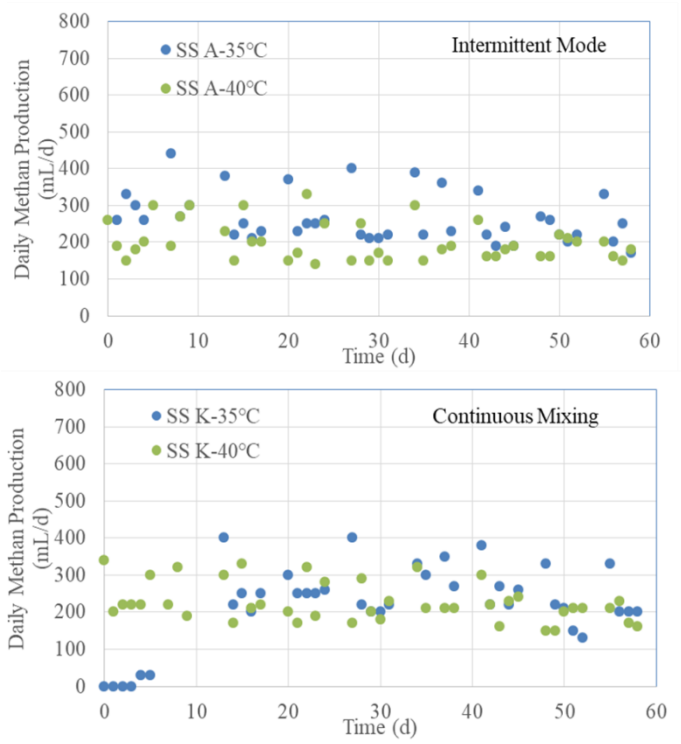

Figure 2. Daily methane production in SS digesters

The mixing of PS increased biomethanation of SS digestion at %64-99. The highest increase was obtained in the CM mode and upper mesophilic level as the lowest performance case. The specific methane yields calculated were 720, 793, and 600 mL CH_4/g VS_{fed}.d for PS, SS and MS digestion, respectively, and were highly above the amounts given in previous studies (Bolzonella et al., 2012, Braguglia et al., 2015; Davidsson et al., 2008; Pinto et al., 2016; Winter and Pearce, 2010). The difference was correlated to high OLRs and/or low HRTs where OLRs over exceeding hydrolyisis rate reduces .

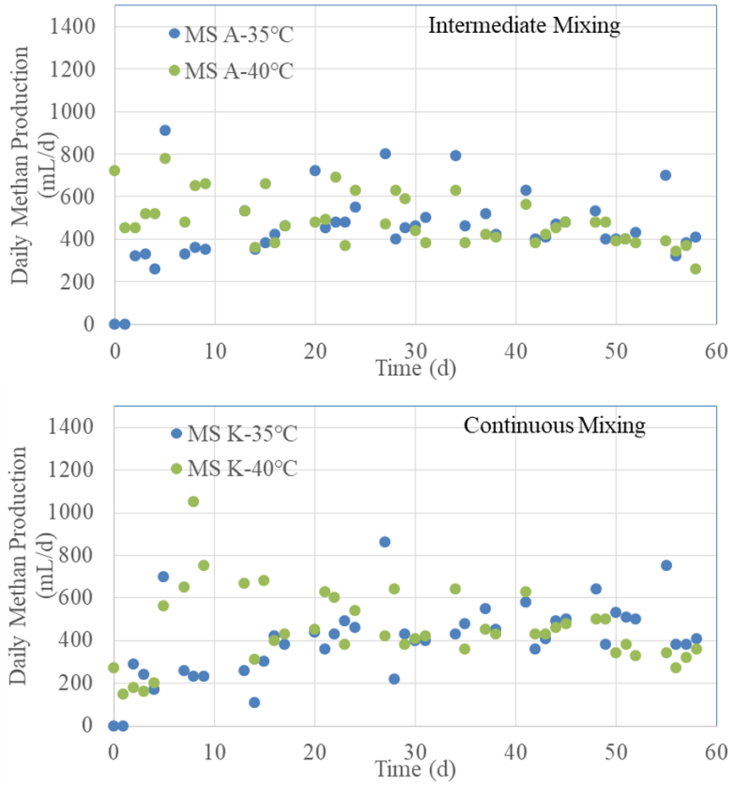

Figure 3. Daily methane production in MS digesters

Upper mesophilic level induced a stable VS concentration level in PS digestion (Figure 4). The decreasing pattern at 35°C indicated a lower biomass activity (growth) as EC reached higher levels whereas lower EC value indicated higher biomass growth as more ions were uptaken by the microbial cells at 40°C of DT (Table 1). The factor was increased hydrolysis, thus, degradable substrate concentration which enhanced biomass concentration, but inhibited acetogenesis or methanogenesis was indicated by reduced methane production rates. Long chain fatty acids (LCFA) are prone to increase in concentration as a result of enhanced hydrolysis of lipids (Abeles et al., 1992). PS is expected to contain a considerable content in lipids (Erdirencelebi and Ebrahimi, 2022).

Upper mesophilic level induced a stable VS/biomass concentration supported by enhanced hydrolysis in SS digestion, EC level was lowered indicating a higher biomass synthesis enhanced by the CM mode (Figure 4). Upper mesophilic level and IM mode can provide a more stable digestion with increased biomass and activity in SS digestion.

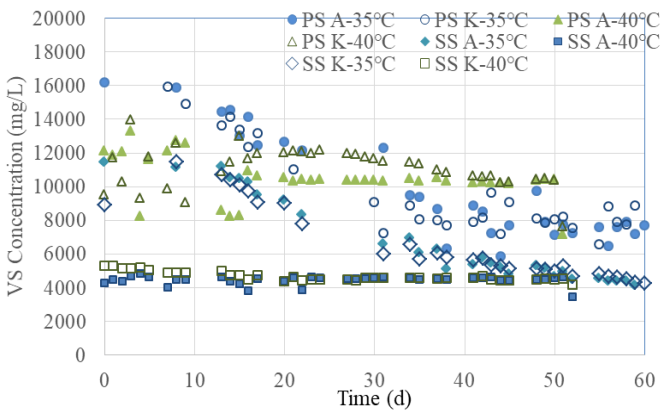

Figure 4. VS Concentration in PS and SS digesters

Table 1. EC levels of stabilized PS and SS

Digester	Units	35°C	40°C
PS A-EC	mS/cm	5.3 (+/-0.1)	4.6 (+/-0.1)
PS K-EC	mS/cm	5.2 (+/-0.1)	4.8 (+/-0.1)
SS A-EC	mS/cm	4.3 (+/-0.1)	4.0 (+/-0.05)
SS K-EC	mS/cm	4.1 (+/-0.1)	3.9 (+/-0.05)

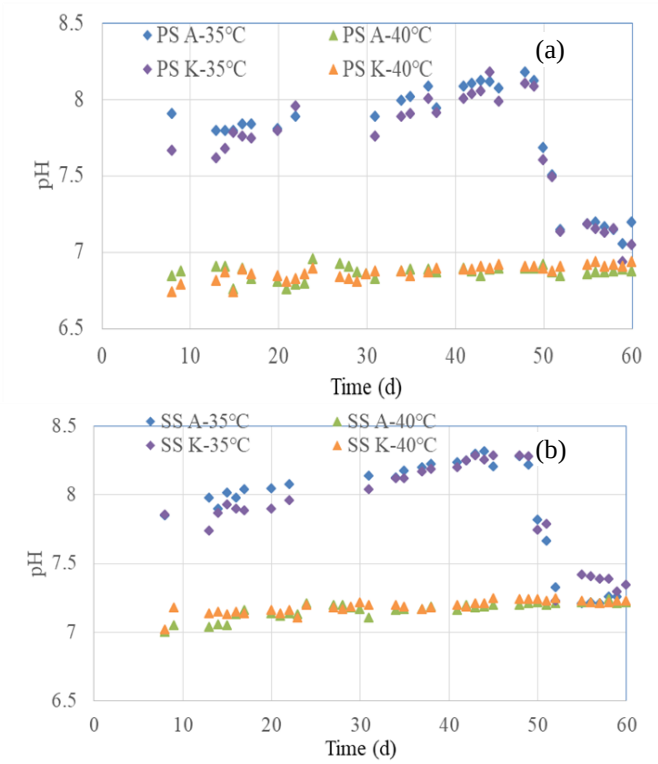

Figure 5. pH level in (a) PS and (b) SS digesters

As pH tends to acidic levels in case of acid producing organics as carbohydrates and lipids and alkali levels as proteins are degraded, any trend in anaerobic digestion can indicate the cause. During digestion at 35°C, pH proceeding at a alkali level over 8.0 indicated protein degradation in SS digestion whereas a lower but a lower but still alkali level over 7.5 presented a balanced degradation of organic types in PS digestion (Figure 5). The pH drop in the last days of 35°C period pointed out to a toxic effect coupled with lowered methanation levels in both digesters. Digestion at 40°C induced much lower pH levels stabilizing around 7.3 and 6.9 in SS and PS digestion, respectively, showed that hydrolysis of carbohydrates and lipids were enhanced mostly, while proteinaceous matter degradation was still dominant in SS digestion. The EPS and protein content reported at a high level in SS supported this finding (Flemming and Wingender, 2001). The lowest pH and methanation levels indicated increase in hydrolytic+acidogenic and decrease in methanogenic activity.

Conclusion and Recommendations

Increasing DT to upper mesophilic level induced denser hydrolysis and acidification reactions resulting in reduction in biomethanation but increase in biomass concentration in both PS and SS digestion. Optimum operational conditions were obtained as IM and 35°C for SS and MS digestion but CM and 35°C promoted methanogenesis at a higher level in PS digestion. DT rise to upper mesophilic level enhanced hydrolysis and acidification reactions but also the inhibitory effect of intermediate products originating from carbohydrates

and lipids as pH tended to drop below neutral level as a result of acidification in PS digestion. Higher pH level in SS digestion indicated a dominantly proteinaceous matter degradation but also enhanced acidification evidenced a higher degree of carbohydrates and lipid degradation due to upper mesophilic temperature in comparison to digestion at 35°C. Monitoring of the intermediate products is needed in PS and SS digestion as it will lead to measures applicable on the process to ameliorate the sewage sludge stabilization system.

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YENİLİKÇİ BİR YALITIM MALZEMESİNİN YANGIN PERFORMANSININ GELENEKSEL YALITIM MALZEMELERİ İLE KIYASLANMASI

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ÖZET

Temel olarak barınmak ve daha birçok amaç için kullandığımız yapılar hayatımızın önemli bir parçasıdır. İçinde yaşadığımız veya çalıştığımız bu yapıların yangına karşı dayanıklı olması; en azından belirli bir süre mukavemetini koruması beklenir. Bu da ancak uygun malzemelerin kullanımı ile mümkündür. Her alanda gelişen teknoloji ile birlikte yapı malzemesi sektörü de gelişmektedir. Her geçen gün yeni ve yenilikçi malzemeler sektöre katılmaktadır. Binalarda kullanılan yalıtım malzemeleri de gelişmekte ve değişmektedir. Bu çalışmada Faz Değişim Malzemesi (FDM) katılmış iç sıva katmanının yangın performansı diğer yalıtım malzemeleri ile karşılaştırmalı olarak araştırılmıştır. Deneysel uygulamalar EN ISO 11925-2 standardında tanımlanmış yöntem ile gerçekleştirilmiştir. İlk olarak standart ile belirlenmiş boyutlarda numuneler hazırlanmıştır. Geleneksel olarak XPS, EPS, Cam yünü ve Taş yünü inşaat sektöründe kullanılan yalıtım malzemeleridir. Hazırlanan tüm numunelere Tek Alev Kaynağı Testi (EN ISO 11925-2) uygulanmıştır. Ayrıca farklı karışım oranlarının (alçı ve FDM) yeni yalıtım malzemesinin yangın performansına etkisi de ayrıntılı olarak incelenmiştir. Termal performans ve yangın performansı açısından en uygun karışım oranı belirlenmiştir. Elde edilen sonuçlar oldukça umut vericidir. Özellikle enerji tasarrufu açısından yapıya fayda sağlayan yeni bir malzemenin pek de araştırılmamış olan yangın dayanımı hakkında fikir sahibi olunmuştur.

Anahtar Kelimeler: Yapı malzemesi, Yangın dayanımı, FDM.

Giriş

Azalan enerji kaynakları ile birlikte binalarda enerji tasarrufu sağlayamak amacıyla ısı yalıtımı uygulaması yapılmaktadır. Özellikle sert kış şartlarında binalarda harcana enerjinin büyük kısmı ısınma maçlıkır. Bu nedenle ısı yalıtımı oldukça önemlidir. Bu amaçla çeşitli malzemeler kullanılmaktadır. Binalarda yaygın olarak kullanılan bazı Isı Yalıtım Malzemeleri şöyle sıralanabilir: Cam yünü, Cüruf yünü, Taş yünü, Poliüretan köpük, Genleştirilmiş polistren (EPS), Ekstrüde polistren köpük (XPS), Polietilen köpük, PVC-polivinilklorür-köpüğü, Elastomerik kauçuk köpüğü, Fenol köpüğü, Melamin köpüğü (TMMO, 2005)

Bu malzemeler binaların dış cephesine, iç cephesine veya ara katman olarak uygulanmaktadır. Bu malzemeler uygulandıktan sonra üzerleri sıva ile kaplanmaktadır. Uygulana bu malzemelerin yangın dayanımları ile ilgili literatürde çalışmalar mevcuttur (Hossain ve ark., 2022; Niziurska ve ark.,2022; Dibya ve ark., 2022; Zhang ve ark., 2022; Wei ve ark., 2022; Bo ve ark., 2022; Choi ve ark., 2022).

Faz değiştiren malzemelerin yapı malzemelerine entegre edimesi ile enerji tasarrufunun yanı sıra enerjiyi depolayan ve gerektiğinde kullanan yapı malzemeleri geliştirmek amaçlanmıştır. Fakat bu malzemelerin kullanımı henüz yaygın olmadığından yangın performansları ile ilgili çok az yayın vardır. Bu yayınlarda da konunun daha fazla araştırmaya ve geliştirmeye açık olduğu özellikle vurgulanmaktadır (Dimos ve ark., 2016; Gnanachelvam ve ark., 2019; Gnanachelvam ve ark., 2020; Gnanachelvam ve ark., 2021; Dionysios ve ark., 2013). Bu çalışma ile henüz çok yeni ve yaygınlaşmamış bir malzemenin FDM li sıvanın yangın performansı EN ISO 11925-2 standardında tanımlanmış yöntem ile araştırılmış ve elde edilen sonuçlar sunulmuştur. Geleneksel olarak EPS ve Taş yünü inşaat sektöründe kullanılan yalıtım malzemeleridir ve hazırlanan karışımın yangın performansını karşılaştırmak amacıyla çalışmaya dahil edilmiştir.

İlk olarak standart ile belirlenmiş boyutlarda numuneler hazırlanmıştır. Hazırlanan tüm numunelere Tek Alev Kaynağı Testi (EN ISO 119252) uygulanmıştır. Ayrıca farklı karışım oranlarının (alçı ve FDM) yeni yalıtım malzemesinin yangın performansına etkisi incelenmiştir.

Materyal ve Metot

Uluslararası Standartlar Örgütü (ISO) tarafından yayınlanan EN ISO 11925-2 standardında, dikey olarak yönlendirilmiş test numuneleri kullanılarak doğrudan küçük alev çarpması ile ürünlerin tutuşabilirliğini tespit etmeye yönelik bir test yöntemi sunulmaktadır. EN ISO 11925-2 standardında sunulan test yöntemi, tutuşabilirliği değerlendirmek için tasarlanmıştır Numunenin yüzeyine veya kenarına küçük bir alev (kibrit boyutunda) uygulanmasının ardından numunenin dikey yüzeyinde alevin 15 veya 30 saniye içinde yayılması ölçülerek ele alınır. Alevli damlacıkların veya parçacıkların oluşmasının belirlenmesi, numunenin altına yerleştirilen filtre kağıdının tutuşup tutuşmadığına bağlıdır.Bu test yapılırken, numune küçük bir alevin doğrudan çarpmasına maruz bırakılır. 250 mm × 90 mm boyutundaki test numunesi, “U” şeklinde bir numune tutucuya dikey olarak takılır. 20 mm yüksekliğinde alev numune ile 45 derece açı ile temas ettirilir. Uygulama noktası, şu şekilde belirlenir:

- Yüzey maruziyeti: yüzey merkez çizgisinin alt kenarının 40 mm yukarısı .
- Kenar maruziyeti: alt kenarın genişliğinin merkezi.
- Alevli döküntülerin düşmesini izlemek için numune tutucunun altına filtre kağıdı yerleştirilir

Ürün sınıfına göre iki farklı alev uygulama süresi ve test süresi kullanılmaktadır: E sınıfı için alev uygulama süresi 15 saniyedir ve alevin uzaklaştırılmasından 20 saniye sonra test sonlandırılır. B, C ve D sınıfları için alev uygulama süresi 30 saniye, testin maksimum süresi alevin çıkarılmasından sonra 60 saniyedir ve alev kaynağının çıkarılmasından sonra herhangi bir tutuşma gözlenmezse veya numunenin yanması durursa test daha erken sonlandırılır (www.eurolab.net,2023). Uygulama koruyucu kıyafet (Yanmaz önlük, yanmaz eldiven) ile gerçekleştirilmiştir. Test düzeneği Şekil 1 de görülmektedir.

Şekil 1. Test Düzeneği

Yer döşemeleri hariç, yapı mamullerinin yangın performansında dikkate alınacak parametreler:

- alev yayılması
- ısı ve duman açığa çıkması
- yanma damlacıkları/tanecikleri

Deney numuneleri 250 mm uzunluğunda ve 60mm genişliğinde imal edilmiştir. Numuneler Şekil 2 de görülmektedir.

FDM+SIVA EPS TAŞ YÜNÜ

Şekil 2. Test numuneleri

Bulgular ve Tartışma

30 saniye alev uygulaması sonraki numunelerin durumu Şekil 3 de verilmiştir. Test sonuçları belirtilen parametreler için Tablo 1 de özetlenmiştir.

TAŞ YÜNÜ **EPS** **%50 FDM** **%30FDM** **%10 FDM**

Şekil 3. Test sonrası numunelerin görünümü

Tablo 1. Test Sonrası Malzeme Sonuçları

TS EN ISO 11925-2	MALZEME	DURUM
Her bir deney numunesi için aşağıdakiler kaydedilir. • Tutuşma olup olmadığı • Alevin uygulandığı noktadan itibaren alev yüksekliğinin 150 mm'ye ulaşıp ulaşmadığı ve bu yüksekliğe alevin ulaşma süresi • Süzgeç kağıdında yanma olup olmadığı • Deney numunesinin fiziksel özellikleriyle ilgili gözlemler	EPS	• Numunelerde tutuşma olmadı. • Alev deney süresi içerisinde 150mm ölçme çizgisine ulaşmadı. • Numunelerde damlama olmadı, filtre kağıdı yanmadı. • Deney numunesinde erime oldu.
	TAŞ YÜNÜ	• Numunelerde tutuşma olmadı. • Alev deney süresi içerisinde 150mm ölçme çizgisine ulaşmadı. • Numunelerde damlama olmadı, filtre kağıdı yanmadı. • Deney numunesinde erime olmadı.
	%50 FDM+ %50 ALÇI	• Numunelerde tutuşma olmadı. • Alev deney süresi içerisinde 150mm ölçme çizgisine ulaşmadı. • Numunelerde damlama olmadı, filtre kağıdı yanmadı. • Deney numunesinde erime olmadı.
	%30 FDM+ %70 ALÇI	• Numunelerde tutuşma olmadı. • Alev deney süresi içerisinde 150mm ölçme çizgisine ulaşmadı. • Numunelerde damlama olmadı, filtre kağıdı yanmadı. • Deney numunesinde erime olmadı.
	%10 FDM+ %90 ALÇI	• Numunelerde tutuşma olmadı. • Alev deney süresi içerisinde 150mm ölçme çizgisine ulaşmadı. • Numunelerde damlama olmadı, filtre kağıdı yanmadı. • Deney numunesinde erime olmadı.

Sonuç ve Öneriler

Değerlendirilen malzemelerden en kötü alev performansını EPS sergilemiştir. Değerlendirilen malzemelerden en iyi alev performansını %50 ve %30 FDM içeren harç sergilemiştir. Taş yünü malzemede ve %10 FDM içeren harç da sadece alev iz bırakmıştır fakat onlarda bile kopma dökülme meydana gelmemiştir. Bu açıdan değerlendirildiğinde FDM-ALÇI karışımı, yapılarda yangın açısından güvenle kullanılabilecek hatta yapıyı yangından koruyabilecek bir malzemedir.

Teşekkür ve Bilgi Notu

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EFFECTIVENESS ANALYSIS OF MINI-CHANNELED SHELL-AND-TUBE HEAT EXCHANGER

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ABSTRACT

Experimental and numerical analysis of a mini-channeled shell-and-tube heat exchanger was carried out in the present study. For the experimental part, a shell-and-tube heat exchanger with a mini-channel diameter of 2.2 mm was manufactured. There are nine mini-channels in the heat exchanger. Each of the mini-channels is made of stainless steel and has a length of 110 mm. Cold and hot fluids entered parallel flow heat exchanger at the same mass flow rate (0.00379 kg s^{-1}). In the experiments, the working fluid used was the deionized water. Inlet temperatures of the cold and hot fluids are 20°C and 60°C, respectively, with an accuracy of ±0.5 °C. The results of the experimental investigation showed that outlet temperatures of the hot and cold fluids were 51.5°C and 28.8°C, respectively. The obtained experimental results were used as validation data for numerical analysis, and the numerical analysis was validated for the flowrate ratio of both fluids of 1 (C_{FR} = 1). The results of the numerical analysis showed that there is a difference of approximately 1.1% for the hot fluid outlet temperature and 2.4% for the cold fluid outlet temperature in comparison with the experimental results. The commercial Ansys Fluent software was used for the numerical part, and analyses were performed for C_{FR} = 1 – 20 range. The ε-NTU (Effectiveness Number of Transfer Units) procedure was applied to examine the effectiveness of the heat exchanger. Results indicated an increase in effectiveness with an increase in the C_{FR} value. For example, at C_{FR} = 10, the effectiveness was calculated as 0.85, and the cold fluid outlet temperature was found to be 54 °C. It was found that at this C_{FR} value, there was an increase of 82.9% in the cold fluid outlet temperature compared to the conditions of C_{FR} =1.

Keywords: minichannel, heat exchanger, numerical analysis, ε-NTU

Introduction

Heat exchangers are devices used in various fields such as power generation/storage plants, HVAC systems, and the food industry. Different types and sizes of heat exchangers are required for applications in these areas. These include shell and tube and plate heat exchangers. In a shell and tube heat exchanger, transfer of heat is based on principle that one fluid passes through tubes while other fluid is circulated around tubes. The performance of a heat exchanger is affected by several parameters, such as the material, length and diameter of the tube that the fluid passes through. Characteristics of flow vary depending on hydraulic diameter. Kandlikar and Grande (2003) classified channels based on their characteristic lengths in their study. In their work, channels with characteristic lengths above 3 mm were classified as macrochannels, while those in the range of 0.2 - 3 mm were classified as minichannels. Heat exchangers are often designed according to ε-NTU method proposed by Kays and London (1987). Researchers have utilized this method to examine the effectiveness of heat exchangers. In an experimental study, Pourahmad and Pesteei (2016) employed turbulators with different angle orientations. They observed that effectiveness increases with an increase in Reynolds number but decreases with a decrease in the angle of the turbulator. Asvapoositkul and Kuansathan (2016) applied ε-NTU method to investigate operating characteristics of an air-cooled heat exchanger. In their study, they developed a new approach to ε-NTU method to determine behavior of air-cooled heat exchanger.

Borjigin et al. (2019) examined cooling efficiencies using both coupled ε-NTU and traditional ε-NTU methods. They explained that effectiveness values obtained using the traditional ε-NTU method were similar to those obtained with the coupled ε-NTU method. Kamsuwan et al. (2023) employed artificial neural networks to enhance the accuracy of simulation results for microchannel heat exchanger analysis. They suggested that embedded artificial neural networks for nano-fluid properties and regression for water properties on CFD could provide more realistic results.

In this study, both the numerical and experimental analysis of a mini-channeled shell-and-tube heat exchanger was performed. ε-NTU method has been used to evaluate performance of the mini-channeled heat exchanger. In experimental and numerical studies, the effect flowrate ratio of hot and cold fluids on effectiveness of heat exchanger was examined.

Materials and Methods

The conducted study involved design and fabrication of mini-channeled heat exchanger. Design of the mini-channeled heat exchanger is presented with Fig. 1. Mini-channels, made of stainless steel, have a diameter of 2.2 mm. The heat exchanger includes nine mini-channels, each with a length of 110 mm, through which the cold fluid passes. The shell surrounding the mini-channels, where the hot fluid flows, has a diameter of 48 mm. The inlet and outlet reservoirs of the cold fluid, separated by a steel plate, are located in the region where the mini-channels connected. The cold fluid entering the heat exchanger is directed towards the mini-channels after coming from the inlet reservoir.

Experimental data were obtained from the experimental setup depicted schematically in Fig. 2. Constant temperature baths ensure that the required inlet temperature values are achieved for both cold and hot fluids. Hot and cold fluid inlet temperatures are 60°C and 20°C (±0.5°C) for this study. T-type thermocouples are used to measure and record temperatures of fluids entering and leaving heat exchanger. Hot and cold fluids are pressurized using pumps and enter heat exchanger at mass flow rate of 0.00379 kg s^{-1}.

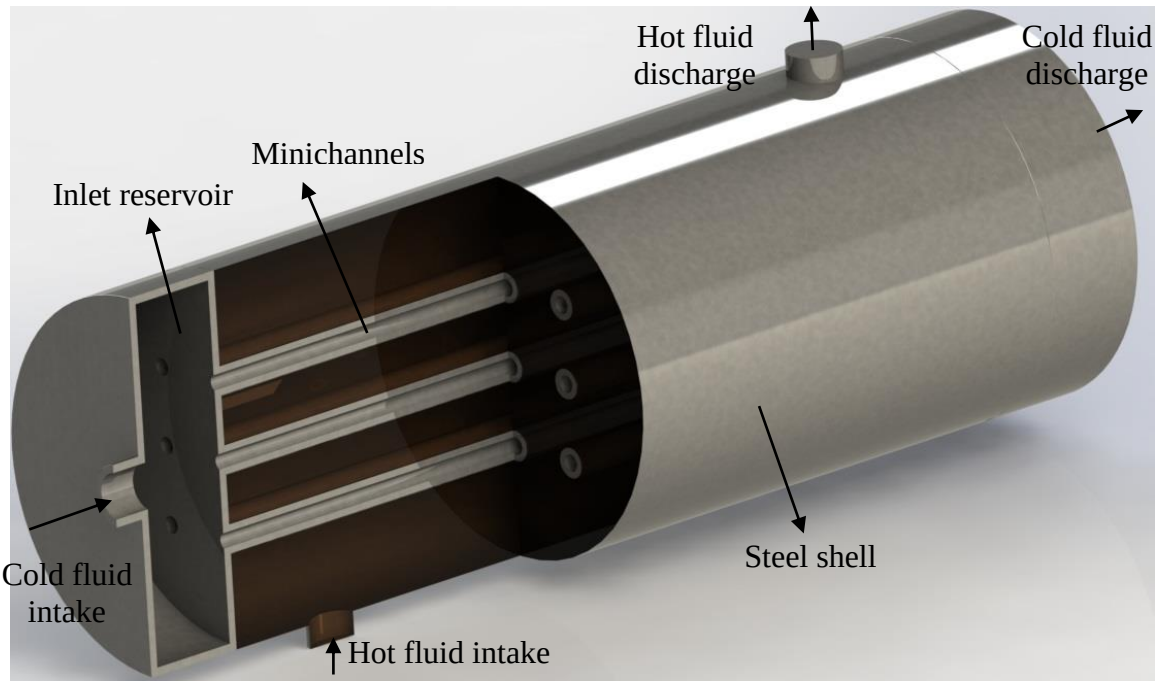
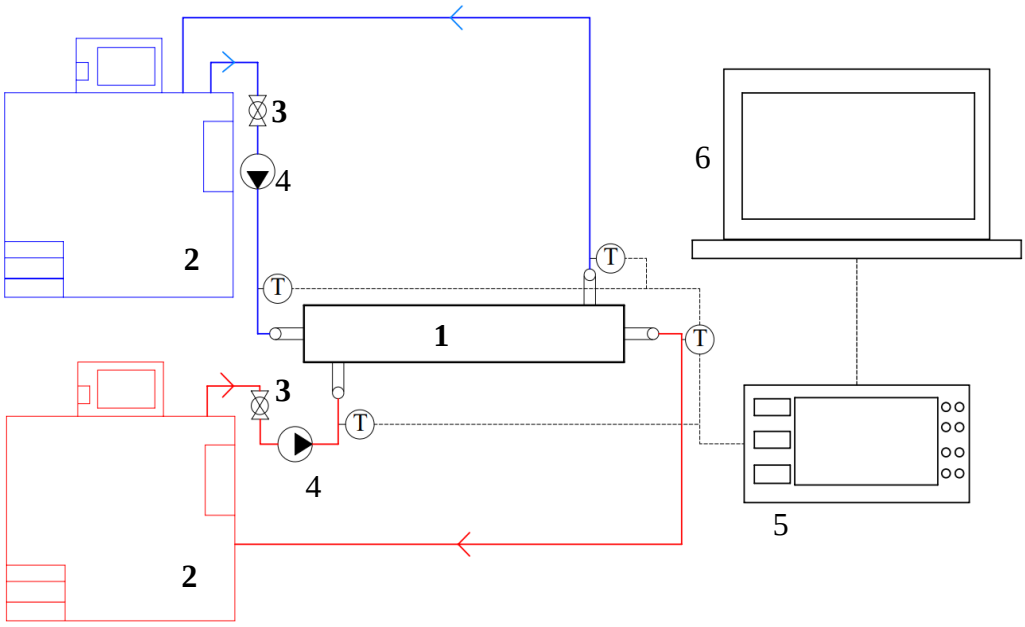


Figure 1. Solid model of mini-channelled heat exchanger

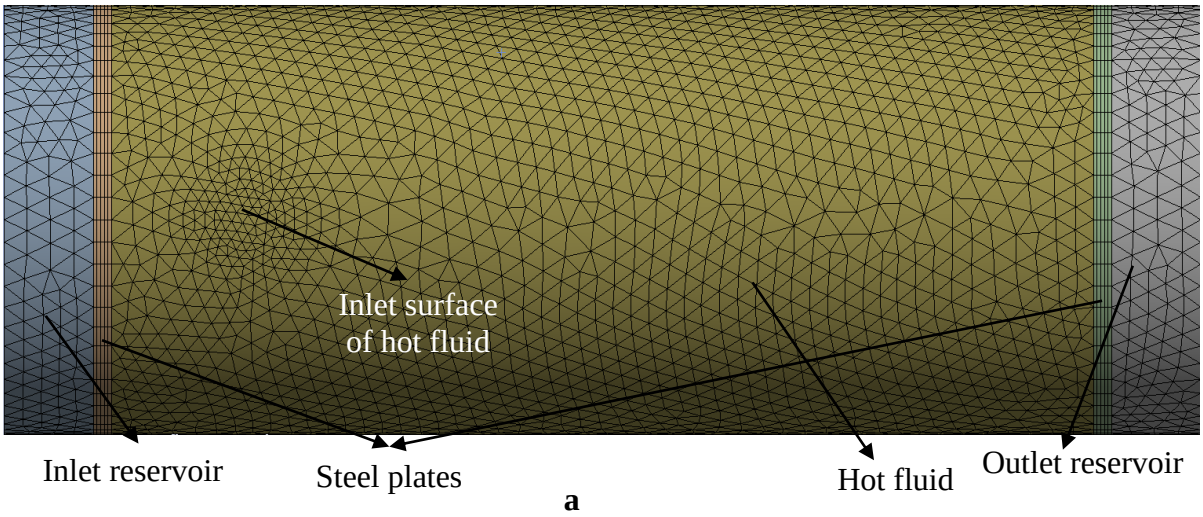


1	Mini-channeled heat exchanger	**4**	Pumps
2	Constant temperature baths	**5**	Datalogger
3	Valves	**6**	Computer

Figure 2. Experimental setup and devices list

Ansys Fluent package program was used for numerical analysis. The numerical model of heat exchanger was created, and model structure is presented in Figs. 3a and b. The total number of grid elements is 3211536.

The SST k-ω turbulence model was applied in numerical analysis, and the coupled solution algorithm was employed. Analyses were conducted in the range of CFR = 1 – 20 in order to investigate effect of flowrate ratio of hot and cold fluids.



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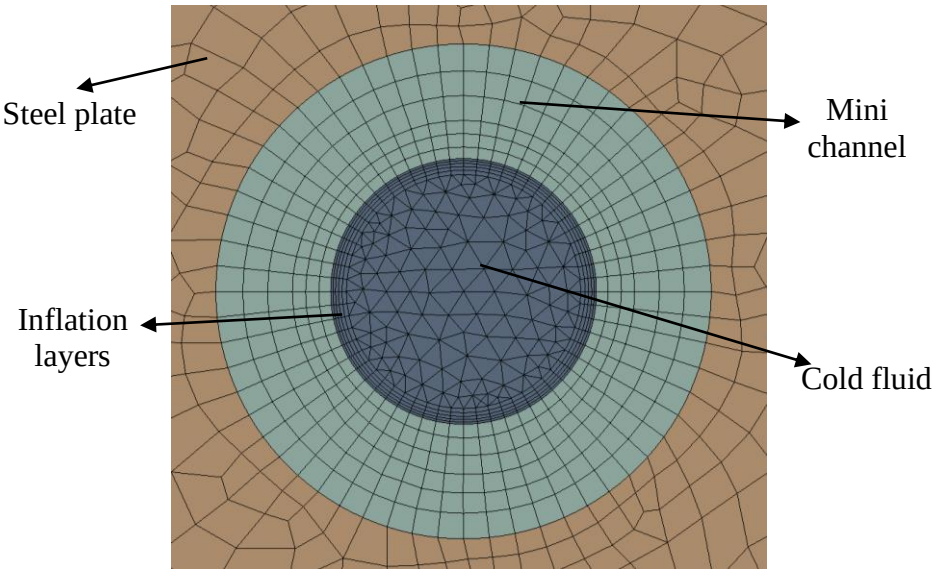

b

Figure 3. Side view of mesh model (a), detail view of mini channel (b)

To examine the effectiveness of heat exchanger, ε-NTU procedure was followed (Incropera and De Witt, 1996). The maximum achievable heat transfer for heat exchanger effectiveness is denoted as $q_{\max}$.

$$q_{\max} = C_{\min}(T_{h,i} - T_{c,i}) \tag{1}$$

$$C_{\min} = \min[\dot{m}_h c_{p,h}, \dot{m}_c c_{p,c}] \tag{2}$$

Here, $C_{\min}$ represents heat capacity rate. It is set equal to heat capacity rate of flow with the lower value between hot and cold flows. $T_{h,i}$ and $T_{c,i}$ denote inlet temperature of the hot and cold fluid, respectively. $\dot{m}_h$ and $\dot{m}_c$ represent the mass flowrate of hot and cold fluids, respectively. Ratio of mass flowrate is given by following equation.

$$C_{FR} = \frac{\dot{m}_h}{\dot{m}_c} \tag{3}$$

The efficiency value is calculated from the following equation.

$$\varepsilon = \frac{C_c(T_{c,o} - T_{c,i})}{C_{\min}(T_{h,i} - T_{c,i})} \tag{4}$$

C_c is the cold fluid heat capacity rate, $T_{c,o}$ and $T_{c,i}$ are the cold fluid outlet and inlet temperatures respectively. NTU value is obtained through following equation:

$$NTU = -\frac{1}{\sqrt{1+c^2}} \ln\left[\frac{2/\varepsilon - 1 - c - \sqrt{1+c^2}}{2/\varepsilon - 1 - c + \sqrt{1+c^2}}\right] \tag{5}$$

$$c = \frac{C_{\min}}{C_{\max}} \tag{6}$$

Here, $C_{\max}$ is taken to be equivalent to the ratio of the capacity of the fluid (either hot or cold) that has a higher capacity.

Findings and Discussion

An experimental study was conducted with the mini-channeled heat exchanger for C_{FR} = 1 and mass flowrate of 0.00379 kg s^{-1}. Deionized water has been chosen as working fluid. Outlet temperatures of cold and hot fluids were obtained as 28.8°C and 51.5°C, respectively. Experimental results were utilized as validation data for numerical analysis. In order to ensure the independence of the results from mesh count, analyses were performed with different mesh numbers, and Table 1. shows the results. It was found that after about three million mesh structures, the results showed negligible changes in the results.

Table 1. Mesh independence

Analyses	Mesh Count	Max. Skewness Value	$T_{c,o}$ [°C] Numerical	$T_{c,o}$ [°C] Experimental	Differences [%]
1	5127978	0.85	29.5	28.8	2.5
2	3211536	0.85	29.5	28.8	2.4
3	1895501	0.85	30.0	28.8	4.0
4	1086204	0.85	29.7	28.8	3.1

Figure 4a shows the changes in effectiveness versus NTU. Effectiveness of heat exchanger reaches 0.57 (ε = 0.57) when C=1. When C=0.1, this value reaches 0.89 (ε = 0.89). The effectiveness value at C=0.1 shows a 56.14% increase compared to C=1. At C = 0.5, ε reaches a level of 0.75. The effectiveness variation in range of C_{FR} = 1 - 20 is shown in Fig. 4b. The effectiveness value exhibits a parabolic increase with the mass flowrate ratio. For C_{FR} = 1, C_{FR} = 10, and C_{FR} = 20, the effectiveness values are calculated as ε = 0.24, ε = 0.85, and ε = 0.94, respectively. When the effectiveness values at C_{FR} = 20 and C_{FR} = 1 are compared, a 291.7% increase is observed.

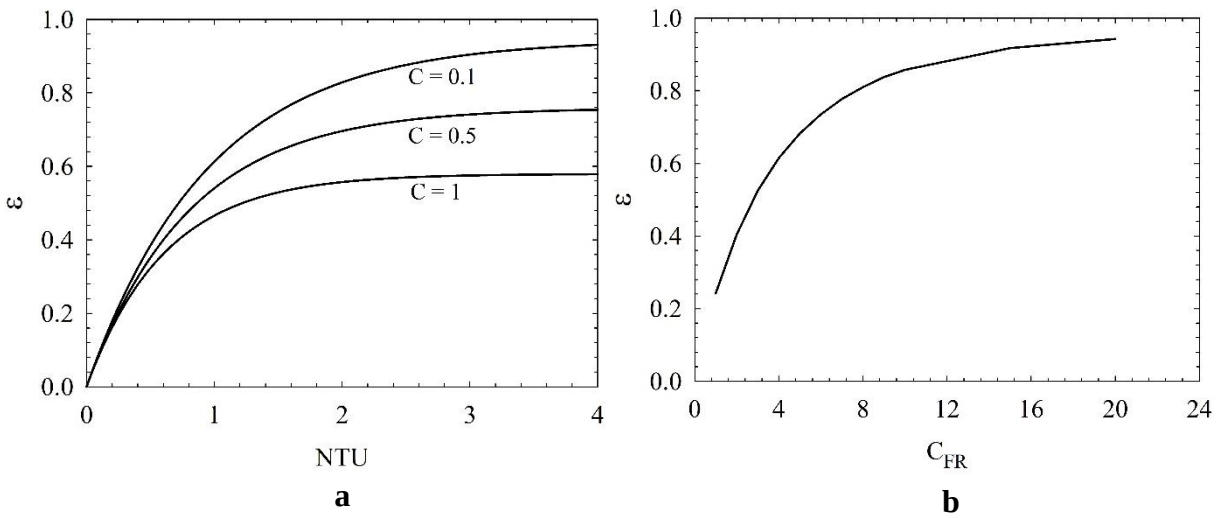

Figure 4. Variation of effectiveness value with NTU (a), with C_{FR} (b)

Figure 5. shows the variation of outlet temperatures of hot and cold deionized water with C_{FR}. When C_{FR} = 1, hot and cold deionized water outlet temperatures are 50.5 °C and 29.5 °C, respectively. When the C_{FR} is 20, $T_{h,o}$ is obtained as 57.7 °C and $T_{c,o}$ is obtained 58.1 °C. Comparing the cold fluid outlet temperatures, a 95.6% increase is observed.

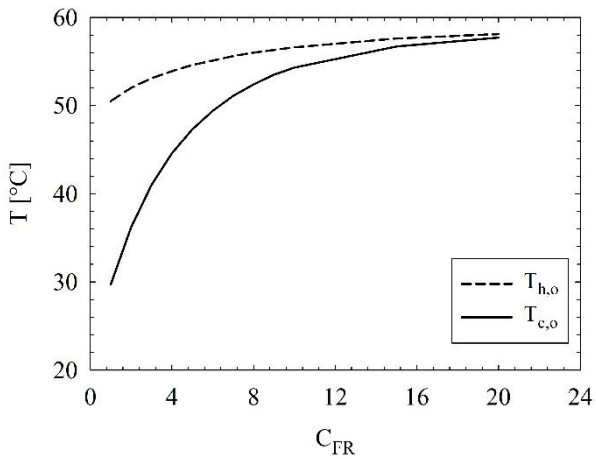

Figure 5. Variation of outlet temperature of fluids with C_{FR}

Conclusion and Recommendations

In this study, experimental and numerical investigations have been carried out on a mini-channeled heat exchanger. Effectiveness of heat exchanger was examined using ε-NTU method. Influence of inlet mass flowrate ratio of hot and cold fluids on effectiveness was also taken into consideration. The conclusions were summarized below:

- The effectiveness increases rapidly up to C_{FR} = 10, and beyond this value, the rate of increase slows down.
- When the effectiveness values are compared at C_{FR} = 20 and C_{FR} = 1, a 291.7% increase was observed.
- At c = 1 the effectiveness (ε) was obtained as 0.57; while, at c c = 0.1, it was obtained as 0.89. This corresponds to an increase of 56.14%.

Thanks and Information Note

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PRODUCTION OF ENERGY EFFICIENT BUILDING ELEMENTS FROM RENEWABLE RESOURCES

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ABSTRACT

Sustainable development is a development model that consider social, economic and environmental aspects and benefits. Due to the depletion of fossil resources and the aggravation of environmental problems due to conventional production and consumption models. Thus, environmentally friendly production methods are getting more preferred techniques. In this study, the production of building elements from perlite composites containing polyurethane, made of biomaterials were studied. Additionally, the thermal properties of these environmentally friendly building elements were investigated. As a result of the work, perlite-bio polyurethane composites with a density of 400 kg/m^3, a compressive strength of 2 MPa and a thermal conductivity coefficient of 0.05 W/mK were produced.

Keywords: Castor oil, polyurethane, biomaterials, perlite, composite materials, thermal conductivity coefficient.

Introduction

Due to the environmental concerns and depletion of fossil reserves, obtaining and production of materials from renewable resources is getting more and more important issue. Animals, plants and microorganisms can be used as renewable resource. Among the renewable resources, plant oil based are getting special attention due to the ease of accessibility and modification (Çakir Hatir, 2019. Koca, 2019. and Espinosa, 2011.). Additionally, many type of pure material can be synthesized.

Plant oil triglycerides are the most used plant oil based materials. The world production was exceeded 210 million tons in 2022. Figure 1 shows the reactive parts of a typical plant oil triglyceride. One can easily modify a typical plant oil triglyceride by using these reactive positions. One of the most used plant oil triglyceride based derivative is epoxidized plant oils. Double bonds of the plant oils are easily converted to epoxy derivatives by using peroxy acids. The most used epoxidized plant oil triglyceride is epoxidized soybean oil. World production of epoxidized soybean oil exceeded 500.000 ton in 2022.

Because of the reactive nature of the epoxy rings, ESO is reacted with carboxylic acids and bio-based polyols are obtained as reaction product. Formic and acetic acids are mainly used carboxylic acids. Besides this type of polyols, naturally hydroxyl group containing plant oil triglycerides are also available (Cayli, 2016.). Castor oil the most produced inherently hydroxyl group containing triglyceride. More than 90 % of castor oil is composed of ricinoleic acid. Figure 2 shows the structure of castor oil and methylene diphenyl diisocyanate. Ricinoleic acid is an 18 carbon containing unsaturated carboxylic acid with a hydroxyl functionality.

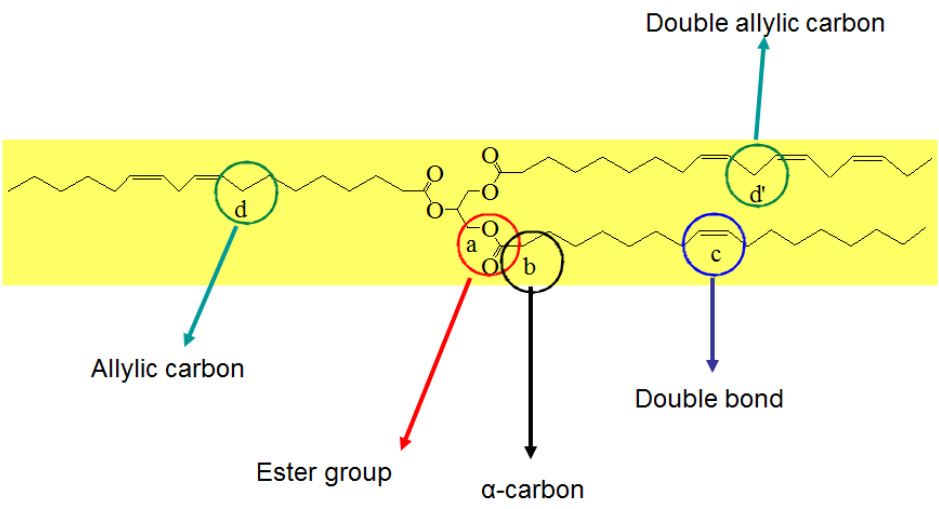

Figure 1. Reactive parts of a typical plant oil triglyceride.

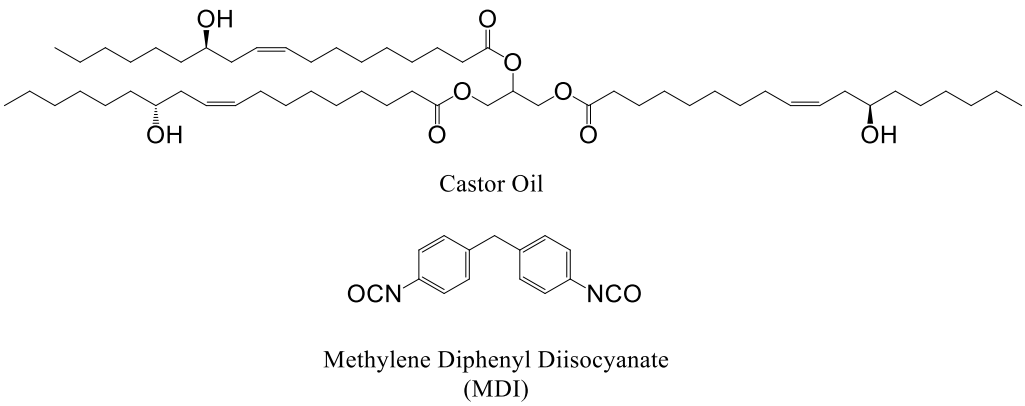

Figure 2. Structure of Castor oil and MDI

Figure 3. Structure of expanded perlite

In 2021 767.000 tons of castor oil was produced. Castor oil is used for many industrial applications. When stoichiometric amount of castor oil is mixed with MDI load bearing and strong bio-based polyurethane is produced. Approximately, 80% of the final polyurethane is composed of castor oil.

Instead of pure polyurethane, composites of this polymer can be preferred due to better mechanical and thermal properties. For the sake of the sustainable development energy efficient materials, synthesis methodologies

and systems are preferred. Polyurethanes are good insulating materials their thermal conductivities is approximately 0,02 W/m.K.

The term "thermal conductivity" describes a material's capacity to conduct or transfer heat. Although 'k' is the most common sign for it, 'λ' and 'κ' can also be used to represent it. Low thermal conductivity materials transmit heat less quickly than high thermal conductivity materials. For example, metals are particularly effective at conducting heat and usually have high thermal conductivity; insulating materials such as polyurethane foam or polyethylene films, on the other hand, have low thermal conductivity. As a result, low thermal conductivity materials are employed as thermal insulation and high thermal conductivity materials are frequently used in heat sink applications.

Moreover one of the most useful fillers with low thermal conductivity is perlite. Usually created by hydrating obsidian, perlite is an amorphous volcanic glass with a comparatively high water content. Perlite mineral usually contains 3-5% water. It's a naturally occurring substance with the peculiar ability to expand significantly when heated enough. This mineral can be used in industry "as ceramic flux to lower the sintering temperature" and is also a useful commercial product due to its low density following processing. Expanded perlite may have bulk densities between 50 / 200 kg/m^3

This study looked at the process of creating building components out of biomaterial-based perlite composites with polyurethane. Furthermore, these eco-friendly construction materials' thermal characteristics were also examined.

Materials and Methods

Castor oil, MDI were purchased from Merck (Darmstadt, Germany) and were used as received. Expanded perlite that had 100 kg/m^3 density was kindly donated by Bergama Mining Company. Compression tests were performed by using Devotrans DVG 25. Thermal Conductivity measurements were performed with TK04 thermal conduc4tivity meter.

Findings and Discussion

Polyurethane synthesized in this study had a density of 0,95 g/ml. On the other hand the perlite used ha a density of 0,1g/ml. Densities of the synthesized polyurethane perlite composites are shown in Figure 4. When the perlite amount was increased, density of the final polyurethane composite decreased. Samples used had a dimensions of 5cmx5cmx5cm and the total volume of the samples was 125 cm^3.

Compression properties was measured by using Stress-strain tester. Compression strength of the pure bio-based polyurethane was determined as 3 MPa. It was noted that compressive strength increased up to 20 5 perlite loading. The highest compressive strength was observed at 5.8 MPa with 20% perlite loading.

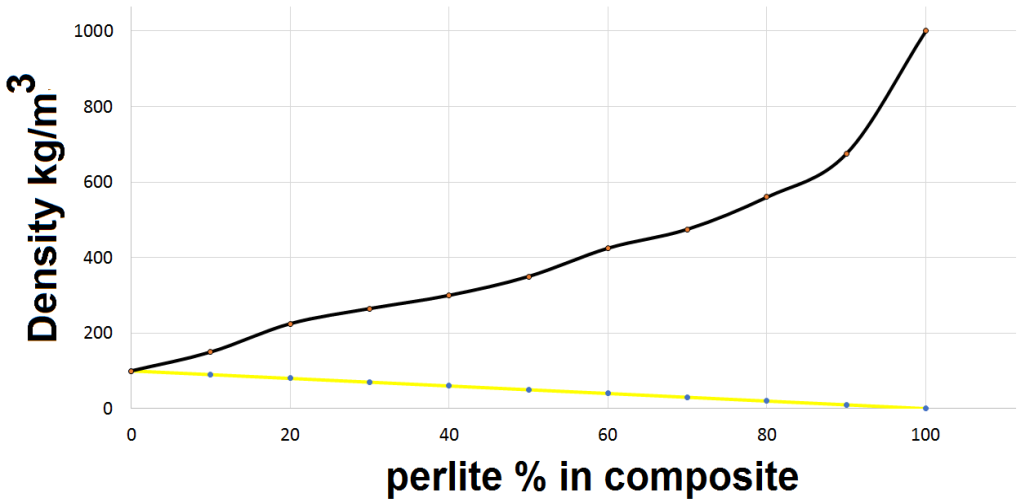

Figure 4. Densities of Perlite7Biopolyurethane composites

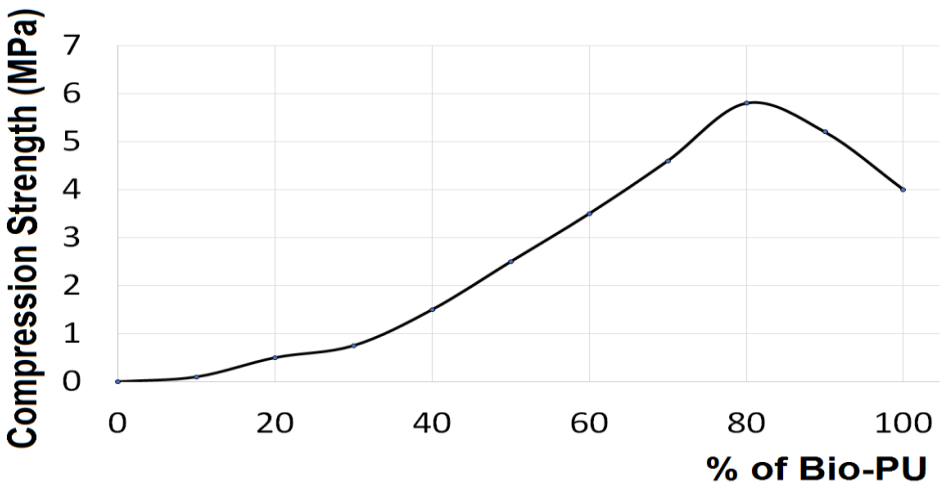

Figure 5. Relation between compressive strength and Bio-PU amount

The lowest compressive strength was observed as 0.2 MPa with 90 % perlite loading. When compared industrially acceptable building blocks, 3,7 and 2,5 MPa compressive strength values would be acceptable. Densities of the perlite-polyurethane composites were measured as 425 and 350 kg/m^3 respectively. The thermal conductivity values at those densities were detected as 0,035 and 0,05 W/m.K.

Conclusion and Recommendations

This study showed that by using cheap starting materials, it is possible to produce building block with a desired properties. Polyurethane component contains 80% bio based material. That makes this polymer more environmentally friendly. The final products shows good mechanical properties with excellent thermal conductivities. Perlite-bio polyurethane composites with a density of 400 kg/m^{3,} a compressive strength of 2 MPa, and a thermal conductivity coefficient of 0.05 W/mK were created as a consequence of the work.

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SYNTHESIS OF MONOGLYCERIDES VIA A NEW ENERGY-EFFICIENT METHOD

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ABSTRACT

Monoglycerides are glycerin monoesters of fatty acids. They are surfactants and therefore have many uses in the food, cosmetics, polymer and medical industries. In production using conventional methods, triglycerides (fatty acid glycerin triesters) are reacted with excess amounts of glycerin in the presence of a basic or an acidic catalyst. The reaction takes place at around 200 ºC and the reaction time is approximately 24 hours on average. Apart from this method, although there are productions in which lipase enzymes are used as catalysts, their stability and the conditions required for this production are not competitive. In the method presented in this study, high-efficiency monoglyceride synthesis is carried out by a reaction called boric acid acidolysis. The reaction is completed at 170 ºC and within 2 hours. The reaction efficiency is over 90%.

Keywords: Triglyceride, monoglyceride, glyceride, boric acid, boric acid ester.

Introduction

Monoglycerides are a type of glyceride that consists of a glycerol molecule bonded to a fatty acid by an ester bond. Two distinct types of monoglycerides can arise from glycerol's primary and secondary alcohol groups: 1-monoacylglycerols, in which the fatty acid is linked to a primary alcohol, and 2-monoacylglycerols, in which the fatty acid is linked to a secondary alcohol. Structures of monoglycerides are shown in Figure 1.

Monoglycerides are versatile materials. They are surface active agent and they are generally used for homogenation purposes. Especially they are used for food additives. Besides food industry, they are also used in cosmetology, healthcare and even construction industries.

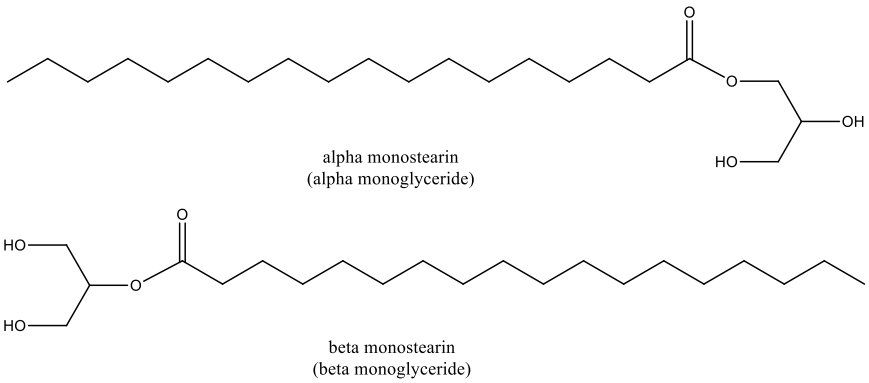

Figure 1. Structure of monoglycerides

Monoglycerides are generally produced acid or base catalyzed transesterification reactions. Plant oil triglyceride is first mixed with a suitable amount of glycerin. Then catalyst is added. Sulfuric acid, toluene sulfonic acid or suitable Lewis acids are sued as acid catalyst. Sodium hydroxide, potassium hydroxide or calcium hydroxide are used as basic catalyst. Reaction mixture is fist heated to 120 ºC then temperature is gradually raised to 240 ºC. All reactions are performed under an inert atmosphere. The yield of the reactions are roughly 50 or 60% (Rarokar., 2017, Feretti., 2012, and Yamaguchi., 1991).

In this work an energy efficient synthesis for monoglycerides is described. The first step of the synthesis is generation of triglyceryl borate ester. Then this ester is reacted with free fatty acids and monoglycerides are produced in 2 hours with a higher yields.

Materials and Methods

Boric acid, butanol, butyric acid, dichloromethane, glycerin, sodium hydroxide, hydrochloric acid, p-toluene sulfonic acid, pyridine, sodium sulfate and toluene were purchased from Merck (Darmstadt, Germany). Oleic acid was obtained by saponification and subsequent acidification of olive oil. Vertex V70 model spectrophotometer was used for infrared (FTIR) characterization and Varian 500 MHz model NMR instrument was used for ^{1}H-NMR characterization.

Synthesis of Triglyceryl Borate

4.58 grams of boric acid was placed in a 250 milliliter flat-bottomed flask. 20.44 grams of anhydrous glycerin and 100 milliliters of toluene were added to it. It was refluxed with the Dean-Stark apparatus in the reflux in an oil bath for 2 hours. At the end of the period, toluene was removed from the environment with a rotary mixer. Triglyceryl borate was obtained and used without any further purification.

Monoolein Synthesis

10.5 grams of triglyceryl borate obtained was placed in a 250 milliliter flat-bottomed flask. 13.3 grams of oleic acid and 0.2 grams of para toluene sulfonic acid (PTSA) were added as a catalyst. It was refluxed in an oil bath at 170 ^{o}C for 2 hours. After monoolein was formed, 100 milliliters of 5% chloric acid is added and crude mixture was stirred vigorously. After this process, the mixture was washed 3 times with 50 milliliters of dichloromethane. Sodium sulfate was then added to absorb water, and it was filtered and dried. Finally, dichloromethane was evaporated in the rotary mixer. And monoolein was synthesized.

Findings and Discussion

Boric acid could be easily converted to borate ester with glycerol. When 3 mol excess of glycerol was mixed with boric acid with the presence of toluene, triglyceryl borate ester was obtained in 1 hours. FTIR spectrum of boric acid and triglyceryl borate is shown in figure 2. After esterification reaction the peak at 3190 cm^{-1} diminished completely. The peak indicates the presence of OH groups that directly attached to boron element.

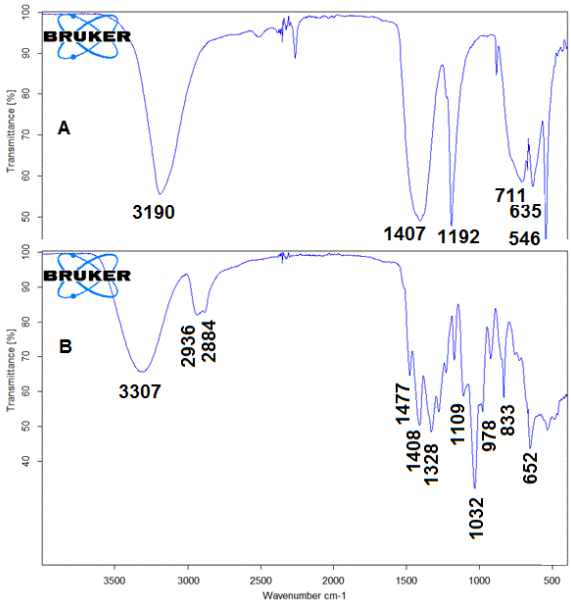

Figure 2. FTIR spectrum of A-Boric acid and B-Triglyceryl borate

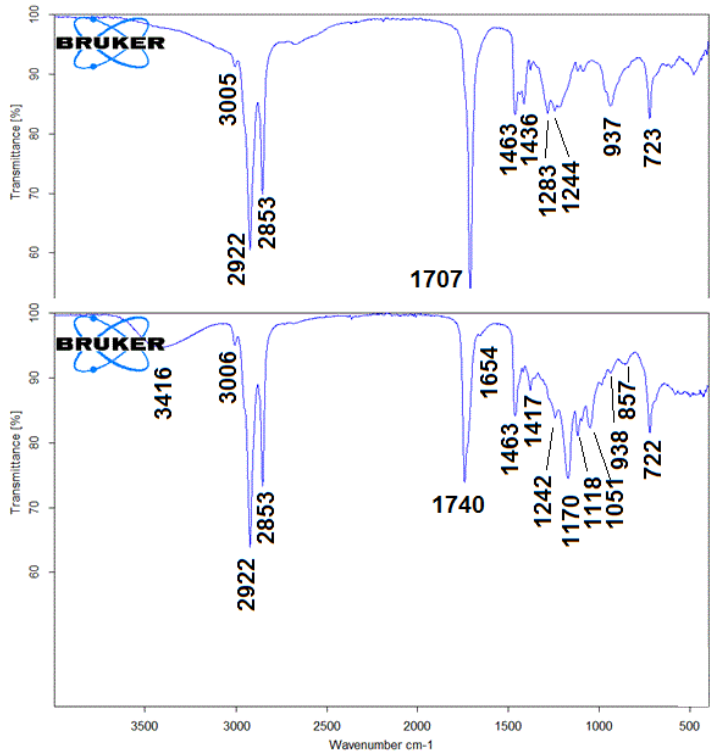

Figure 3. FTIR spectrum of A-oleic acid and B-monoolein

When triglyceryl borate ester reacted with oleic acid at 170 °C, monoolein was obtained with high yields. FTIR spectrum of oleic acid and monoolein is depicted at figure 2. Synthesized monoolein spectrum is so different than triglyceryl borate and oleic acid spectrum. The characteristic peaks of monoolein appear at 3416, 1740 and 1170 cm^{-1}

Additionally ^{1}H NMR spectrum also verify the structure of monoolein. The spectra is exhibited at figure 4. Hydrogens of double bonds appears at 5,5 ppm. Ester hydrogens are depicted also at 4,2 ppm.

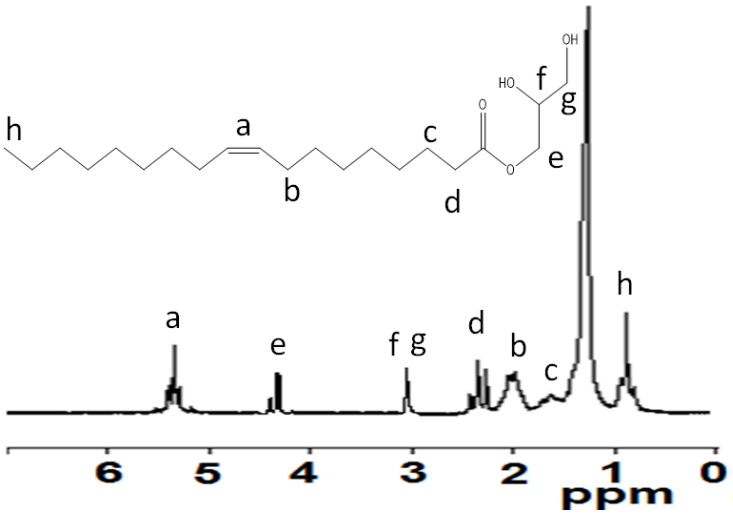

Figure 4. ^{1}H NMR spectrum of monoolein

Reaction conditions for conventional and boric acid ester synthesis are compared at Table 1. It is obvious that new boric acid ester methodology is better than conventional synthesis with regarding to yield and purity.

Table 1. Comparison of Conventional Methods and Boric Acid Method

Method Name	Acidic Catalyst	Basic Catalyst	Boric Acid Acidolysis
Temperature (ºC)	220-240	220-240	170
Time (hour)	24	24	2
Yield (%)	%50-60	%50-60	> %90

Conclusion and Recommendations

As a conclusion, this work reveals a new method that better than conventional methods. As an alternative to conventional methods with acid or base catalysts, which take 24 hours at 240 ºC and are completed with 50% efficiency, this new method, which is completed at 170 ºC in 2 hours and with at least 97% efficiency, is both energy efficient and a more environmentally friendly method.

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ENERGY EFFICIENCY AND GREEN TRANSFORMATION: AN EXAMPLE OF AN INDUSTRIAL FACILITY

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ABSTRACT

Energy efficiency, which came to the agenda of the EU energy policy in the 1970s, has become the basis of energy and climate change issues worldwide over time. This importance has increased even more with the publication of the European Green Deal and the European Recovery Fund in 2019. According to the recommendations of the European Commission and the European Parliament, greenhouse gas reduction targets have been revised and a new energy system has been modelled. It has been shown that achieving these targets will require significant amounts of renewable energy and energy savings. In parallel with global trends, Turkey has also taken important steps in energy efficiency. In this context, it has established many renewable energy sources and encouraged energy saving. In this study, the energy-saving potential, carbon emission effect, and payback period of investment were analyzed through an industrial facility operating in the Organized Industrial Zone. An energy efficiency change is planned for the lighting system, which accounts for approximately 15% of the facility's overall energy consumption. This change has been made with motion sensors and more efficient LED luminaires instead of the existing fluorescent luminaires. According to the results of the analysis, 227 kWh of electrical energy was saved per month and 108 kg of carbon emissions were reduced as environmental impact. In addition, the new system was found to be approximately 3.23 times more efficient than the existing system. The results of the study show that energy efficiency and green transformation not only provide environmental benefits but also offer economic advantages. The proposed scenarios are applicable by industrial organizations taking into account criteria such as initial investment cost, energy savings, and payback period. By adopting such measures quickly, industrial enterprises in Turkey can maintain their competitive advantage with European Union countries and be better prepared for future challenges such as the carbon tax.

Keywords: Lighting, LED, Energy Efficiency, Green Transformation, Cost Analysis

Introduction

After the Industrial Revolution, the continuous increase in carbon emissions and the unplanned use of energy have negative impacts worldwide, creating an unsustainable cycle. Electrical energy is a valuable and limited energy source and is widely used worldwide. This important energy source should be used effectively and economically. In this context, various measures have been taken and incentivized to save energy consumption in our country. Finally, with the Presidential Decree published on 04.11.2023, the previously set 15% energy saving target was increased to at least 30% by 2030 to use energy efficiently and reduce costs in public buildings that are obliged to have energy managers (C.B.Circular 2023/15). These regulations in the public sector show that Turkey keeps its commitments to energy efficiency up to date and improves them. Such regulations should be considered as important steps to raise awareness of energy efficiency and promote sustainable energy use. Further expansion of these efforts in the future may have a critical role in raising the level of awareness of energy consumption and promoting sustainable energy practices.

The evolution of lighting technology enables important steps to be taken in the efficient use of electrical energy worldwide. The savings to be achieved by the efficient use of electrical energy is an important advantage with results that can be felt quickly, especially in the field of lighting. The fact that 20% of the total electrical energy in our country is used for lighting emphasizes the potential contribution of savings in this field to the national economy. In this context, studies examining efficiency and savings in lighting systems have become an important area of focus for researchers.

Various studies have been carried out in recent years to minimize energy consumption in lighting systems and to improve lighting performance. The most common of these studies is retrofit applications that enable the replacement of components in lighting systems for more efficient use of energy. This application, which includes the conversion of fluorescent and LED lighting devices, has been widely adopted to save energy and reduce environmental impact.

As an example of studies in this field, Yılmaz and Sungur examined the LED conversion of a school and observed that approximately 40% energy savings were achieved and emphasised the applicability of this conversion to all public buildings (Yılmaz & Sungur, 2020). In another study, Canol et al. examined the usage scenarios of LED tubes with different efficiency and found that high efficiency LED tubes are 57% more efficient than fluorescent tubes (Canol et al., 2023).

Uyan et al. created an energy efficient lighting system design by focusing on daylight, LED and user behaviour in different parts of a marine equipment manufacturing facility and found that they were able to save approximately 64% energy compared to the initial situation (Uyan et al., 2023).

In another study, Yılmaz et al. designed luminaires that are 40-60% more efficient than fluorescent luminaires by focusing on LED light source, luminaire body, LED driver, optics and light angle as an alternative to 4*18 W fluorescent office luminaires (Yılmaz et al., 2019).

In their study, Bayhan and Avci observed that by using LED light sources in plant cultivation, high yields of crops were grown with low energy consumption (Bayhan & Avci, 2019).

Duman and Güler designed a system using off-grid batteries and LEDs under M4 and M5 road lighting for the northern, central, and southern regions of Turkey. As a result of the study, it was determined that the depreciation period is not applicable because it is more than the economic operating time of the system (Duman & Güler, 2019).

Jordan et al. observed that by using daylight and different lighting control methods, they achieved approximately 20% energy savings with fluorescent and approximately 70% energy savings with LED (Jordan et al., 2020).

Çelik et al. showed that replacing fluorescent lamps with LED lamps with opal emitters increases energy efficiency and illuminance distribution, as well as maintaining clean lighting points to effectively utilize natural lighting (Çelik et al., 2019). Shannon carried out a retrofit of a daylight-adjustable PLC-controlled retrofit throughout an industrial facility, making energy consumption 2.5 times more efficient than before (Shannon, 2018).

This study presents a unique method to achieve energy saving and more efficient lighting in lighting systems used in industrial areas. The study on the replacement of traditional high bay luminaires used in industrial areas with efficient high bay LED luminaires with special angled lenses by adding a motion sensor offers a different approach from other studies in the literature. The application was carried out in the field, energy measurements were made with an electronic electricity meter and the results obtained by comparing the luminous intensity values in the simulation with the real situation.

Materyal ve Metot

This study presents a unique method to achieve energy saving and more efficient lighting in lighting systems used in industrial areas. The study on the replacement of traditional high bay luminaires used in industrial areas with efficient high bay LED luminaires with special angled lenses by adding a motion sensor offers a different approach from other studies in the literature. The application was carried out in the field, energy measurements were made with a submeter, and the results obtained by comparing the luminous intensity values in the simulation with the real situation.

In this study, an applicable saving method in the lighting system used in a certain section of an industrial establishment operating in Çerkezköy Organised Industrial Zone is discussed. This section is actively used 24 hours a day, 7 days a week and the existing lighting system is provided by fluorescent luminaires. In the first stage of the study, 1-month energy consumption of the existing lighting system was determined with the help of a filtering meter. Then, for the selection of LED luminaires, modelling of the current situation and efficient high bay LED luminaires with special angled lenses of different power were made using DIALux evo 12.0 version. Considering the power consumption and the number of luminaires in the modelling process, the 125 W LED luminaire, which is considered to be the most suitable, was installed in the area with the motion sensor and the energy consumption for 1 month was measured by means of a filtering meter. For LED luminaires with other power values, power measurement was carried out with the meter by taking 1-hour data for each of them.

By analysing the data obtained, reduced carbon emission, energy efficiency status, cost calculation, and depreciation period were determined. These analyses reveal the amount of energy saved, the reduction in carbon emissions and the economic return period of the investment by evaluating the effect of the applied LED luminaires on energy efficiency.

Table 1. Measurement equipment technical data sheet

Lightmeter Data Sheet		Electronic Electricity Meter Data Sheet	
Reading Accuracy	±5% (Reading) ±0.5% f.s	Nominal Voltage	220V
Screen Resolution	0.1 Lux/FC	Operating Voltage Range	150V - 300V
Max/Min Feature	There is	Nominal (Base) Current	5(100)A
Operating Temperature	0°C ... 40°C	Frequency	50 Hz ± 10%
Maximum Measuring Range	400,000 Lux	Meter Constant	3000 imp/kWh
Cable Length	150 cm	Accuracy(Class)	Class 1 (TS EN 62052-11, TS EN 62053-21)
Measurement Units	FC/Lux	Power Consumption in Current Circuit	<4 va
Dimensions	170 x 80 x 40 mm	Power Consumption in Voltage Circuit	<2w,10va
Weight	390 gr	Battery Lifetime	Min. 10 Years
Power Supply	1 x 9V Battery	Operating Temperature Range	-40˚C~+85˚C

The technical specifications of the luminance level and energy consumption measurements of the luxmeter and electronic electricity meter are shown in Table 1. These measuring instruments were preferred because they are economical and give accurate results.

Figure 1. Lightmeter

Figure 2. Electronic electric meter

The visuals of the Luxmeter and electricity meter where the measurements were made are shown in Figure 1 and Figure 2.

Findings and Discussion

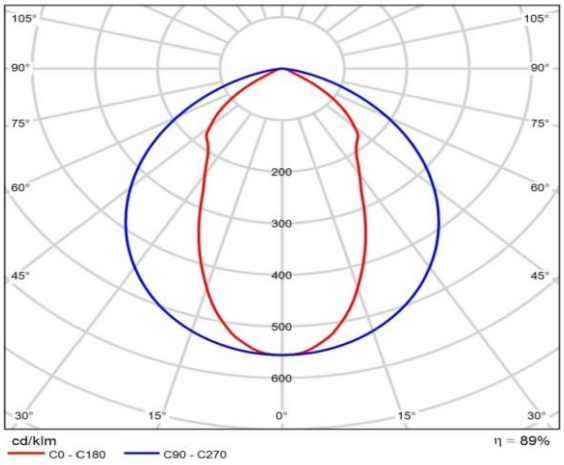
The industrial area examined in the study is 17.5 m long, 7 m wide and 5.2 m high. In the illumination of this area, analyses were made for commercial LED products of different powers. In the luminaire selection, high ceiling LED luminaire with special angled lens with high efficiency was preferred. Technical specifications of these luminaires with different power values are given in Table 2.

Table 2. Technical specifications of the luminaires examined

Luminaire Type	Consumption Power	Lumen Value	Efficiency	Warranty Period	Colour Temperature	Colour Rendering Index (CRI)	Diffuser Type
LED-BUS 50 W High Bay LED Luminaire	50 W	7200 lm	144 lm/W	10 Years	7200 K	>80	Opal diffuser / PMMA / Special Angle Lens
LED-BUS 75 W High Bay LED Luminaire	75 W	10800 lm	144 lm/W	10 Years	6500 K	>80	Opal diffuser / PMMA / Special Angle Lens
LED-BUS 100 W High Bay LED Luminaire	100 W	14500 lm	145 lm/W	10 Years	6500 K	>80	Opal diffuser / PMMA / Special Angle Lens
LED-BUS 125 W High Bay LED Luminaire	125 W	18000 lm	144 lm/W	10 Years	6500 K	>80	Opal diffuser / PMMA / Special Angle Lens
LED-BUS 150 W High Bay LED Luminaire	150 W	21600 lm	144 lm/W	10 Years	4000 K	>80	Opal diffuser / PMMA / Special Angle Lens
Floresan Luminaire	166 W	11008 lm	66 lm/W	2 Years	3850 K	>80	Opal diffuser / PMMA / Special Angle Lens

When the luminaire efficiency values given in Table 2 are analysed, it is seen that LED lamps are 2.18 times more efficient than fluorescent lamps. In addition, when compared in terms of lifetime, it is seen that there is an 8-year difference between LED and fluorescent luminaires.

The light distribution curves of fluorescent and LED lamps obtained with the help of DIALux program are shown in Figure 3 and Figure 4. Red lines give the light distribution in candela/klumen in the C0-180 degree axis parallel to the ground, and blue lines give the light distribution in candela/klumen in the C90-270 degree axis perpendicular to the ground



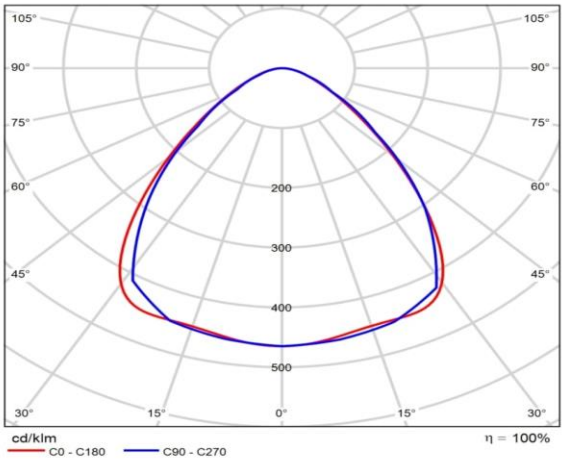


Figure 3. Fluorescent light distribution curve **Figure 4.** 125 W LED light distribution curve

The light environment view of the examined area in DIALux environment is also shown in Figure 5 and Figure 6.

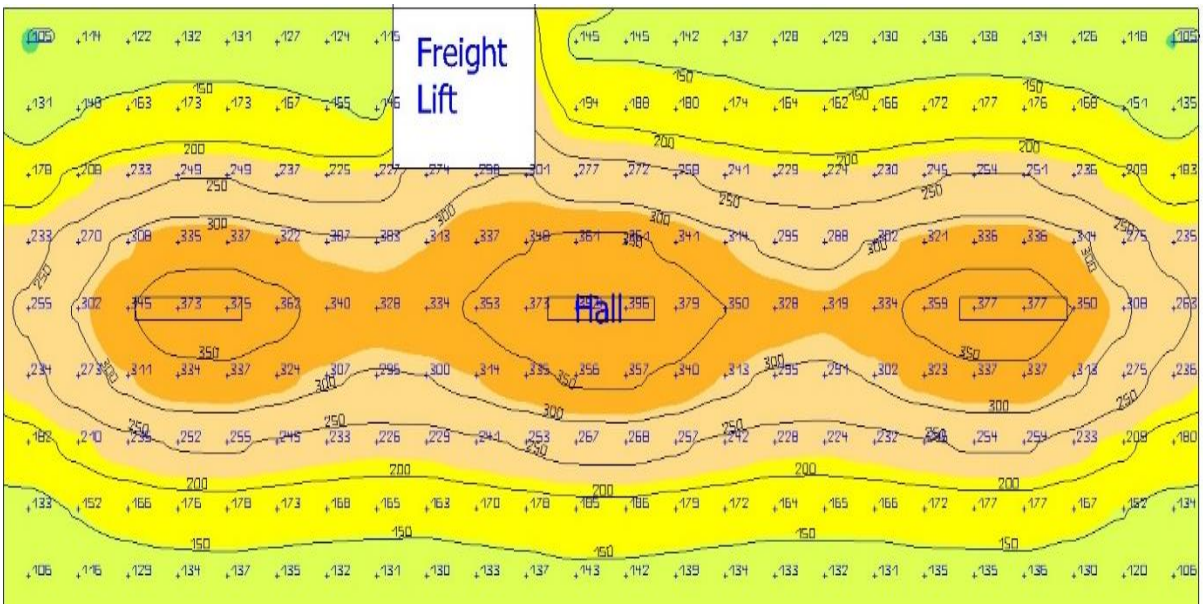


Figure 5. Fluorescent lamp light surrounding view in DIALux program

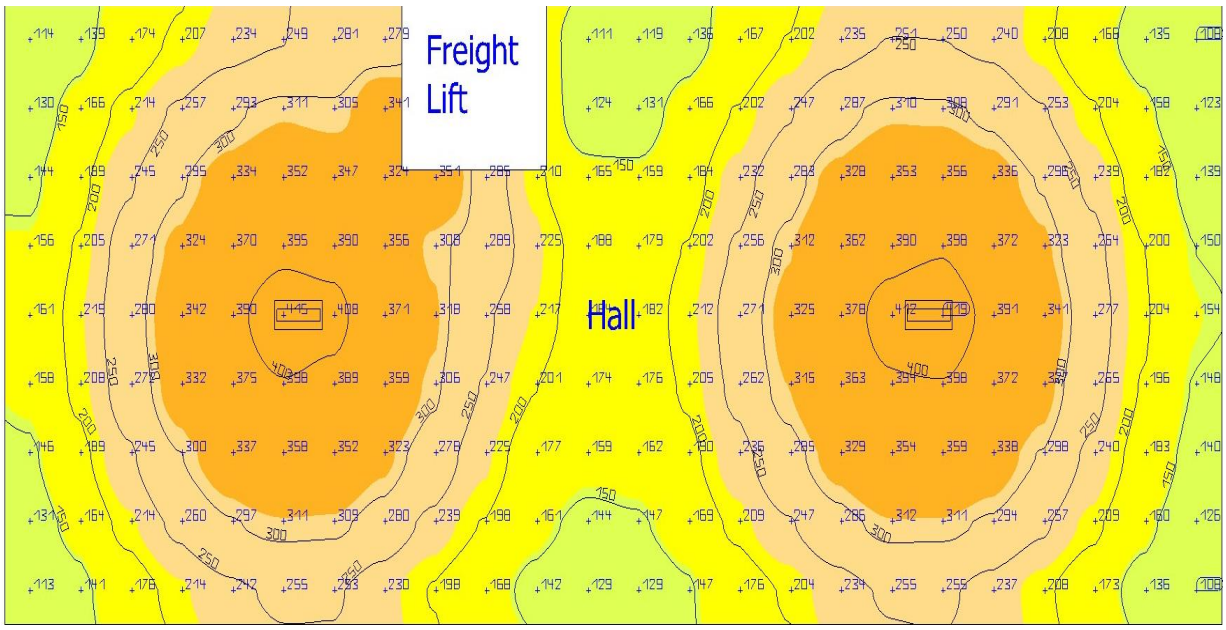


Figure 6. 125W LED lamp light surrounding view in DIALux program

When the light environment views in Figure 5 and Figure 6 are examined, it is seen that they are approximately the same at the minimum brightness level, while Figure 6 is higher at the maximum brightness level.

Modeling the Study Area in DIALux

It has been determined that the average light level in the work area where the freight elevator is located, where there is constant human traffic, should be 200 lux according to TS EN 12464-1 standard. In the DIALux program, the area of 17.5 meters long, 7 meters wide, and 5.2 meters high was modelled, taking into account the wall, floor and ceiling features. The results obtained for the brightness levels of LED and fluorescent fixtures of different powers are given in Table 3.

Table 3. Modelling results of luminaires with different power values

Luminaire Power and Type	Number of Luminaires (Pieces)	Average Illuminance Level (E)	Min. Illuminance Level (Emin)	Max. Illuminance Level (Emax)	Average Uniformity (Uo)
50 W LED	6	233	151	293	0,65
75 W LED	3	217	125	291	0,58
100 W LED	3	291	167	391	0,57
125 W LED	2	248	107	417	0,43
150 W LED	2	297	129	497	0,43
160 W Floresan	3	228	103	398	0,45

As seen in Table 3, luminaires with different power luminaires have the same luminaire efficiency.

It gave very different values on modelling results and energy consumption measurements. The 125 W LED luminaire, which can provide a better average illuminance level with fewer luminaires than fluorescent lighting and has a higher minimum illuminance level, is the luminaire to be focused on in the table.

Energy Consumption Analysis

In this study, a filtering electricity meter was used to measure the electricity consumption data of LED and 160 W fluorescent luminaires with 5 different powers. In the first stage, the hourly energy consumption of the currently used fluorescent luminaire and LED luminaires of various powers was measured. Figure 7 shows the field installation of the LED luminaire with motion sensor in the study area.

Figure 7. LED luminaire installation and final view

The cost of the project was determined as 7,500 TL in total, including 2 125 W lamps, motion sensor, cable, installation, and commissioning. The 1-month energy consumption data of the high-efficiency LED luminaire was measured with the help of an electronic electric meter. With this measurement, it was determined how many hours the sensor-operated lamps were switched on for 1 month.

To evaluate the relationship between project cost and energy savings, these data were used to analyse important parameters such as return on investment, reduction in carbon emissions, and energy efficiency. In the analyses, the economic and environmental impacts of the project were evaluated and data were obtained to demonstrate the effectiveness of similar applications in terms of sustainability.

Table 4 shows the energy consumption, cost and depreciation periods of LED luminaires of different powers.

Table 4. Investment cost and depreciation calculation table

Luminaire Power and Type	LED Consumption	Number of LED	Energy Consumed in Sensorless	Energy Consumed With Sensor	Investment Cost	Continuous Operation Savings	Sensor Saving Amount	Sensor Saving Amount	Amortization Period
	kWh		kWh/ Month	kWh/ Month	TL	TL/ Month	TL/ Month	TL/ 10 Year	Month
50 W LED	47,5	6	205,2	123,3	₺11.730,00	₺351,49	₺583,26	₺69.991,20	20,1
75 W LED	71	3	153,4	92,1	₺8.700,00	₺498,19	₺671,56	₺80.587,20	13
100 W LED	96	3	207,4	124,6	₺9.390,00	₺345,37	₺589,58	₺70.749,60	15,9
125 W LED	117,5	2	169,2	101,6	₺7.500,00	₺453,37	₺644,67	₺77.360,40	11,6
150 W LED	142,5	2	205,2	123,3	₺8.500,00	₺351,49	₺583,37	₺70.004,40	14,6

Considering the calculations in Table 4, it was decided to select the 125 W LED luminaire according to the optimum cost and amortization period calculation. With the use of this luminaire together with the motion sensor, it is calculated that 227.8 kWh energy saving is achieved monthly. This saving amount means that 1302 kg of carbon emissions can be prevented annually. In addition, it was seen that the amortisation period of the investment cost was realised in a short period of 11.6 months and at the end of 10 years, an economic saving of 77,348 TL was achieved. The financial results obtained in this study show that the project is economically efficient in the long term.

The energy consumption of the existing fluorescent luminaire and the selected LED luminaire with and without sensors is shown inn Figure 6.

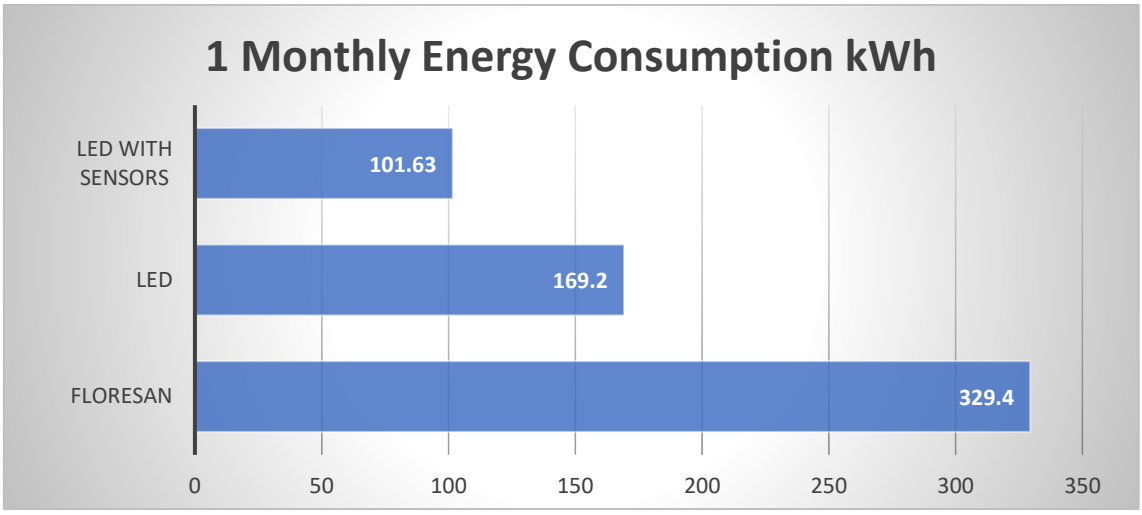


Figure 6. Savings amounts of LED luminaire only and LED luminaire with sensor

According to the comparison results, the average illuminance level increased from 228 Lux to 248 Lux by using 2 125 W LED luminaires instead of 3 166 W fluorescent luminaires, but the average uniformity (Uo) value decreased from 0.45 to 0.43. As can be seen in Figure 6, energy consumption decreased from 329.4 kWh to 101.63 kWh, saving 227 kWh in energy consumption and increasing efficiency by 3.23 times. Since the lighting system is controlled by a motion sensor, the amount of savings may vary slightly depending on the personnel mobility in the area.

Conclusion

This study analyses a transformation process to increase energy efficiency in the field of lighting and evaluates whether it is economically feasible to perform this transformation, especially in industrial facilities. The development of LED technology has popularised the transformation of lighting systems by making it possible to offer energy efficient and affordable LED lamps. As a result of the transition from fluorescent lighting to LED lighting in the studied area, 227.8 kWh of energy savings were achieved per month. Thanks to this energy saving, 1302 kg less carbon is emitted to the nature per month. Considering the investment cost, it is seen that the installed lighting system will pay for itself in a short period of 11.6 months.

The first step for such a retrofit application is to determine the average illuminance levels by the standards in the areas to be converted. The determined levels should be simulated with different luminaire types and powers and designed with appropriate lighting control methods. Technical and economic analyses should be made and energy consumption and savings should be evaluated.

The focus of this study is to compare the performance and test the efficiency of luminaire types of different power in a specific area before carrying out a widespread lighting conversion across the entire facility. This is intended to make an evaluation based on concrete data before a wider conversion decision.

In line with the results obtained from the study carried out for a certain part of the facility, it is predicted that more efficient and more economical results can be obtained by performing LED conversion in the lighting system of the entire facility.

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EFFECT OF MAGNESIUM SLAG PRODUCED BY THERMOCHEMICAL REDUCTION ON GRINDING BEHAVIOR AND ENERGY EFFICIENCY

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ABSTRACT

Since 2016, Turkey has started to produce domestic magnesium metal from dolomite mines in its facility in an integrated manner for the first time, including in Europe. In the facility, A mixture of dolomite, ferrosilicate and fluorite raw materials is ground and magnesium metal is obtained due to thermochemical reduction in reduction furnaces, and 60,000 tons of slag annually are stored in the facility area without any further processing. As a result of research, it has been revealed that the chemical and mineralogical structure of magnesium production slag is similar to Portland cement clinker. Although the effect of the mineral structure of Portland cement clinker cooling conditions on the grinding efficiency is known, the impact of the mineral structure of magnesium production slag on the grinding efficiency has not yet been explained. This study investigated the effect of the mineral structure of magnesium production slag on micron and nanoscale grinding efficiency. Quantitative phase analysis was performed using X-ray diffraction (XRD) of magnesium production slag samples obtained by allowing them to self-cool under different temperature conditions. The crumbling behaviour of magnesium production slag samples was analyzed using the top-down approach. Micron and nanoscale productions were carried out using magnesium production slag samples with the top-down approach. Grinding efficiency was evaluated based on product size and energy consumption.

Keywords: Magnesium Slag, Cement, Grinding, Energy

1. Introduction

After the reduction process of raw materials in the magnesium metal production facility in Turkey, 165 tons of the remaining reaction material per day is stored in the open stock area of the factory without recycling as magnesium production slag. Annually, this amount is over 60,000 tons (Figure 1.1). A secondary magnesium production facility is planned to be established in 2023. Thus, the amount of waste material remaining without annual recycling will exceed 120,000 tons. Unfortunately, dealing with such environmental problems is difficult and costly. Returning magnesium production slag to the system during magnesium production is impossible. As a result, magnesium production costs are increasing, and our country's industry is experiencing difficulties competing with the Chinese market.

Figure 1.1 Magnesium slag storage space

Many studies are carried out on waste use, disposal, and management worldwide and in our country. It is common for metallurgical wastes to be evaluated in the construction industry, mainly by researchers. At the same time, the construction industry serves as a recycling process, contributing to the reduction of environmental pollution due to the disposal of unsuitable products. The main chemical components of magnesium production slag are Fe_2O_3, SiO_2, Al_2O_3 and CaO, similar to those in Portland cement clinker. For this reason, there is no harm in using magnesium production slag as an additive material in cement mortars. Lu et al. (2013), Limestone, used as the primary raw material source in cement production, was replaced with magnesium production slag at 0, 10, 20, 30, 40 and 50%, and the resulting clinker raw composition was sintered. Young and Yang (2019) used high magnesium and low silicon iron ore tailings (IOT) as raw materials instead of clay to produce Portland cement clinker. Deng et al. (2014) proved that, in the early period of hydration, in the pozzolanic types of cement produced with magnesium production slag additive, the pozzolanic effect rate weakens with the increase in the contribution rate of magnesium production slag. Cai et al. (2011) decided that using slaked magnesium production slag as raw material and additive for Portland Cement could be another alternative method. However, as a result of literature research, more academic studies on the grindability of magnesium slag are needed. However, grindability is very important in cement production due to two critical factors. First, the properties of cement depend on its fineness and particle size distribution, as well as its chemical and mineralogical composition. Later, 1/3 of the energy expenditure in the cost of cement is spent on grinding.

Literature studies show that one of the most significant factors in the grinding of clinker is the microstructure's type and amount of phases. Considering that 40% of cement production costs are spent on grinding energy, it is obvious how vital clinker grinding is. Inevitably, changes in the amounts of phases within the magnesium production slag due to changes made in the magnesium production slag process will not affect the grindability. There will be differences in the grindability of magnesium slag samples produced at different temperatures. One of the most important points here is to see the effect of thermal activation on the microstructure and grindability of magnesium slags by keeping the cooling rate constant. Although it is known that the alite mineral in clinker increases with temperature and that the alite mineral facilitates grinding, the effect of different thermal activation on grindability has yet to be mentioned, and no literature study on this subject has been found. For this reason, the impact of magnesium production slag samples produced at different temperatures on the mineral phase amounts, grindability and grinding energy costs under the same cooling conditions (self-cooling) were investigated for the first time within the scope of this paper.

80% more energy can be consumed in grinding hard clinker than soft clinker. Approximately 2% of the electrical energy produced in the world is realized in grinding processes, and the continuous increase in various studies on the grindability of clinker in recent years shows the importance of grinding (Altun and Ölmez, 2001). In this paper, it is aimed to facilitate the grinding of magnesium production slag samples by changing the amount of mineral phases in the microstructure of magnesium slag samples produced by thermal activation and thus to reduce energy costs.

2. Materıal and Method

Industrial trial studies were carried out at the Primary Magnesium Production Facility of Kar Madencilik Company, operating in the Emirdağ district of Afyonkarahisar Province. The facility has 16 reduction furnaces that work independently of each other and where thermochemical reactions are carried out. There are 58 retort tubes in a reduction furnace that feed the raw material mixture required for magnesium metal production. 180 kg of pellets (crude mixture the size of ground granulated almonds) are fed into each retort tube. On average, 15-16% of the fed pellets are produced as crown magnesium, while 84-85% are obtained as magnesium production slag (waste) (Figure 2.1). Magnesium slag (MS) was produced at three different temperatures within the scope of industrial testing (Table 2.1).

Table 2.1 Thermal activation sche me of magnesium slag

	CODES	Temperature (ºC)	Cooling Method
Industrial Tests	MS-1	1200-1250	Outdoor Self-Cooling
	MS-2	1250-1300	Outdoor Self-Cooling
	MS-3	1300-1350	Outdoor Self-Cooling

Figure 2.1 Thermal activation (a) and Self-cooling of magnesium slag in outdoor (b)

The XRF device chemically analysed three magnesium slags obtained at different temperatures. Then, using the chemical analysis results, mineral phase determinations were calculated from Bogue module calculations. Then, magnesium slag samples produced by self-cooling at different temperatures were subjected to a grinding time of 60 minutes in a laboratory-type Bond ball mill with a Ø305×305 mm diameter (Figure 2.2). The obtained products were checked for particle size and size distribution on a master sizer device. The microstructures of the samples used in experimental studies were imaged using the LEO 1430 VP model SEM device.

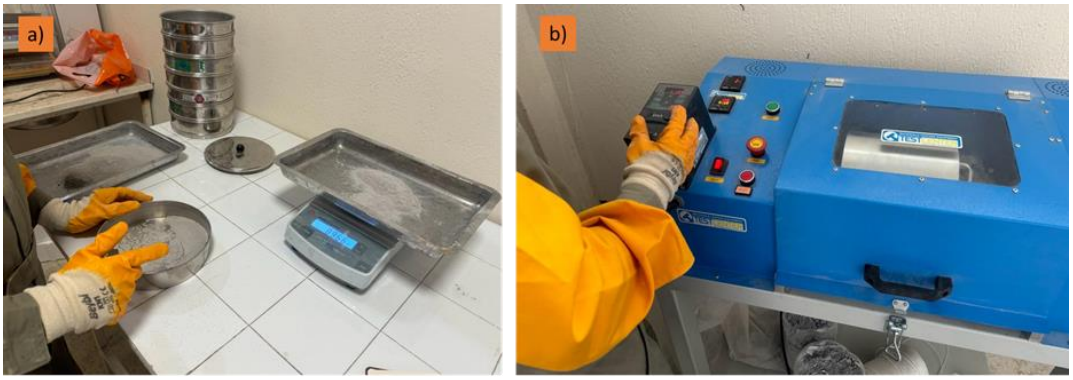

Figure 2.2 Grinding studies and Laboratory scale ball mill used in grinding studies

The Bond method is the most widely used approach in designing the grinding circuits of the ore preparation plants. This method determines the mill size and power requirement for an ore to be ground. In the cement grinding stage, bond work indexes of clinker and magnesium slag samples subjected to thermal activation are first found separately. The primary purpose of calculating bond work indexes is to get an idea about the grinding energy consumption of materials for composite cement production based on the work index of clinker.

3. Results and Discussion

Clinker contains oxides in its composition. These oxides form calcium silicate and aluminium silicate compounds in different proportions depending on the stoichiometric values, the temperature at which the clinker is heated in the kiln and the degree of cooling at the kiln exit. Limestone and clay, the primary raw materials of clinker, are not found in nature in a hundred per cent pure form. For this reason, there are also foreign substances in the raw materials; at the end of the day, they are included in the cement composition in minor proportions. Therefore, besides the main components such as CaO, SiO2, Al2O3 and Fe2O3, which make up 90% of Portland types of cement, there are also MgO, SO3 and alkali oxides. Alite, belite, aluminate, and ferrite, which are the main phases of clinker formation, are formed at high temperatures. Approximately 90% of cement clinker compounds consist of alite, belite, aluminate and ferrite (Mindess et al., 2003). Cement compounds are generally measured using Bogue models proposed 1955 (Equations 1-4). In other words, cement chemical components and R.H. According to Bogue, potential phase amounts can be calculated. The prerequisite for this calculation is the crystallization of the clinker melt in equilibrium with the solid phases. Stoichiometric phases are pure C3S, C2S, C3A and C4AF phases. Bogue models that will calculate the amounts of CaO, SiO2, Al2O3 and Fe2O3 according to their initial raw oxides when their chemical compositions are defined are shown in equations 1-4 (Bogue, 1995): Magnesium production obtained by self-cooling at different temperatures under industrial conditions to be used in the Bogue formula calculation. The chemical contents of the slag samples were calculated using the XRF method, and the results are shown in Table 3.1.

$$C_3S\% = (\%4{,}0710\times CaO) - (7{,}6024\times SiO_2\%) - (6{,}7187\times Al_2O_3\%) - (1{,}4297\times Fe_2O_3\%) \quad (1)$$

$$C_2S\ \% = -(\%3{,}0710\times CaO) + (8{,}6024\times \%SiO_2) + (5{,}0683\times \%Al_2O_3) + (1{,}0785\times \%Fe_2O_3) = (2{,}8675\times \%SiO_2) - (0{,}7544\times C_3S\% \quad (2)$$

$$C_3A\% = (2{,}6504\times Al_2O_3\%) - (1{,}6920\times Fe_2O_3\%) \quad (3)$$

$$C_4AF\% = (3{,}0432\times Fe_2O_3\%) \quad (4)$$

Table 3.1. MS chemical analysis results obtained after the industrial trials.

Temperature/ Cooling Type	Sample Name	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Toplam
		%	%	%	%	%	%	%	%	%
1400-1450 ºC / Speedy mechanical cooling	Clinker	21.14	5.28	3.87	66.25	1.31	0,58	0.38	0.73	98.96
1200-1250 ºC/ Outdoor Self-Cooling	MS-1	28,83	0,41	3,64	64,16	2,05	0,37	0,00	0,04	99,94
1250-1300 ºC/ Outdoor Self-Cooling	MS-2	27,79	0,45	3,19	63,26	4,12	0,35	0,13	0,02	99,77
1300-1350 ºC/ Outdoor Self-Cooling	MS-3	27,02	0,42	3,71	66,06	2,72	0,02	0,11	0,02	99,95

Using the chemical analysis results of magnesium production slag clinkers, as explained in Table 3.1, MS phase amounts and moduli were calculated according to the Bogue model. The results are shown in Table 3.2.

Table 3.2 Mineral phase percentages of MS samples obtained after the industrial trial.

Temperature/ Cooling Type	Sample Name	LSF	S.M.	A.M.	H.M.	C_3S	C_2S	C_3A	C_4AF
		%	%	%	%	%	%	%	%
1400-1450 ºC /Speedy mechanical cooling	Clinker	97.51	2.31	1.36	2.19	66.36	10.64	7.44	11.78
1200-1250 ºC/ Outdoor Self-Cooling	MS1	76,77	7.12	0.11	1.85	28,73	60,99	-5.07	11.08
1250-1300 ºC/ Outdoor Self-Cooling	MS2	78.34	6.68	0.12	1.98	32.56	55,26	-5.06	11.29
1300-1350 ºC/ Outdoor Self-Cooling	MS3	84,37	7,48	0.13	2.17	50,23	39,59	-4.28	9,71

Grinding of clinker cannot be examined only as a mechanical event but also as a complex physico-chemical behaviour that plays a vital role on the surface of the clinker. In general, the grindability of clinker decreases as the Silicate Module (SM) increases, is directly proportional to the amount of Al_2O_3 and Fe_2O_3, and increases linearly with the amount of alite. In addition, grinding aids have significant effects on grinding (Altun and Ölmez, 2001). Chemical and mineralogical composition plays a vital role in the grindability of clinker. It was observed that as SM increased, grindability decreased, and as the amount of Al_2O_3 and free CaO increased, grindability also reduced. This is valid for the same raw materials and the same process conditions. Metallic particles and Fe_2O_3 augment grindability by enabling the formation and growth of microcracks. According to Duda, high amounts of C_3S (Alite) increase grindability, while high doses of C_2S (Belite) decrease it.

Additionally, when the (C_3S / C_2S) ratio or the ratio of silicates to intermediate phases, (C_3S + C_2S) / (C_3A + C_4AF), decreases, eating becomes complex and energy expenditure increases. In addition to chemical and mineralogical components, microstructure also affects grindability. Heating and cooling rates and oven type are also effective in the formation of microstructure (Altun, 1999). The fine crystalline structure improves grinding, especially the tiny calcium silicate crystals. Large crystals make fragmentation more difficult and increase the number of fracture sites. Thus, surface area activity increases, agglomerate is formed and energy losses increase (Altun and Ölmez, 2001).

Cement clinker must be cooled so quickly from the sintering temperature that the amount of C_3S can be preserved as much as possible. In slow cooling, C_2S and C_3A are formed due to the reaction of the clinker melt with a specific ratio of C_3S. In addition, C_3S is not stable below 1250 ºC and tends to decompose into C_2S and free CaO. Divalent iron within the C_3S crystal lattice promotes this dissociation. Therefore, clinker requires rapid cooling for these reactions to occur. In addition, it must be cooled rapidly to properly affect the reaction ability of C3A (the solidification rate of the cement). Rapid cooling is also advantageous when MgO is more significant than 2.5 wt%. Because this is how small periclases are formed. The effects of a high cooling rate (>40 K/min) are as follows.

- Grinding improves due to stress cracks in the clinker.
- There is no alite dissolution, and the amount of this phase is high.
- Cement solidification of the fine crystalline aluminate and ferrite phases formed by shock cooling of the clinker slows down.
- If minor expansion MgO is more significant than 2.5 wt%, volumetric stability is better because free MgO is finely crystalline as periclase (Altun, 2000).

During the slow cooling of the clinker, alite partially dissolves into belite and CaO. At this stage, aluminates, ferrites and very small belite crystallize (Altun, 2000).

Chemical and mineralogical composition plays an essential role in the grindability of clinker. It is observed that the grindability decreases with the increase in the silicate modulus, aluminium oxide and free calcium oxide determined by the chemical analysis of the clinker. The silicate modules of magnesium slags formed due to thermal activation are higher than clinker. Clinker phases are formed due to the reactions that occur while cooking raw meal powder in the rotary kiln. These phases affect the behaviour of the clinker and,

therefore the cement. The main phases of typical Portland cement clinker are: Alite (Tricalcium Silicate-C_3S), Belite (Dicalcium Silicate-C_2S), C_3A (Tricalcium aluminate), C_4AF (Tetracalcium Alumina Ferrite) Alite/Belite ratio and (Alite+Belite)/(in clinker phases When C_3A+C_4AF) decreases, eating becomes difficult (Güllü, 2006). Among the samples used in the study, clinker had the highest amount of alite minerals. After thermal activation, alite minerals gradually increased in the magnesium slag samples. However, since magnesium slags were not cooled temporarily and were left to cool on their own in the open air, the tendency for C_3S to turn into C_2S increased, causing the C_2S amounts of magnesium slags to be higher than that of clickers. This makes grinding magnesium slags more difficult than clicker. Figure 3.1 shows SEM images of magnesium slag samples obtained from thermal activation.

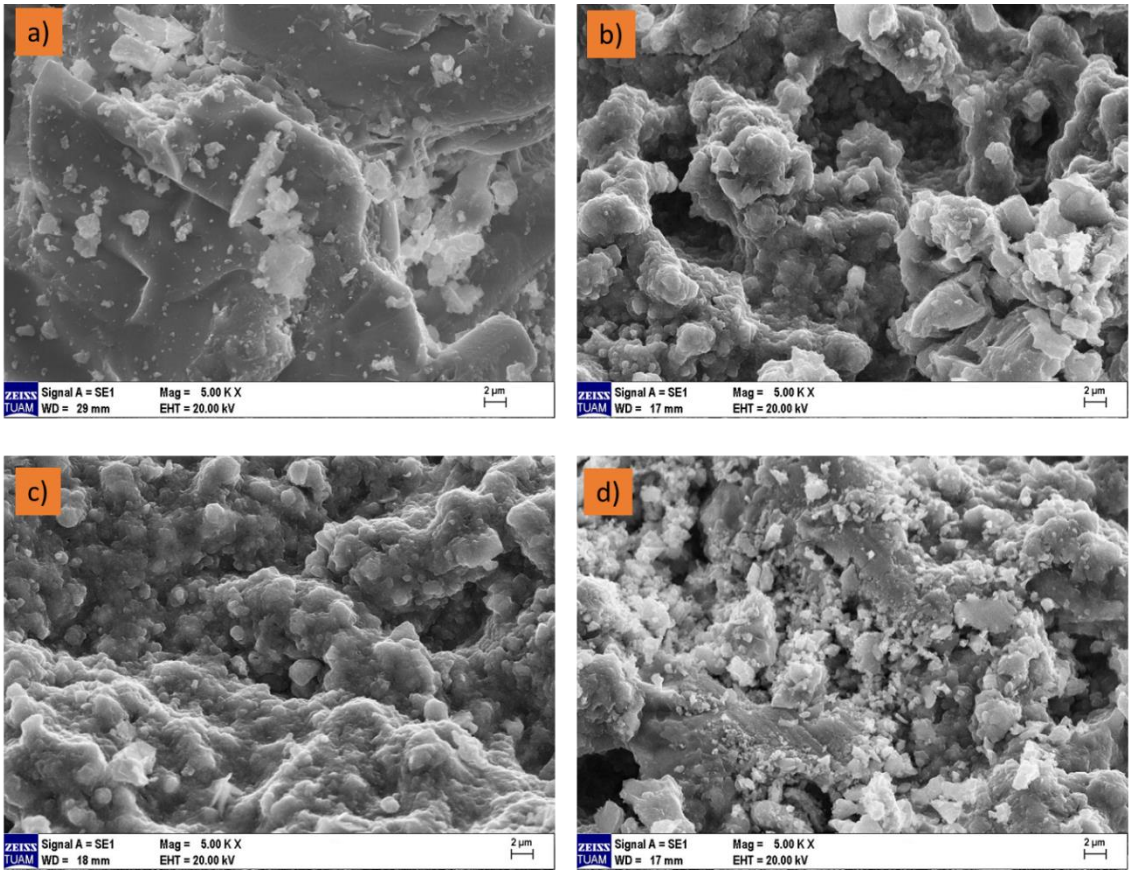

Figure 3.1 Samples of magnesium slag produced as a result of thermal activation; clinker (a), 1200-1250 ºC MS (b), 1250-1300 ºC MS (c) 1300-1350 ºC MS (d)

According to the SEM images in Figure 3.1, magnesium slag gained a tighter microstructure with increasing thermal activation. It can be seen in Figure 3.1 that after thermal activation, the circular-shaped alite mineral phase decreased and the more angular alite mineral phase increased. The grain size distribution graphs obtained after 60 minutes of grinding of Portland cement and magnesium slag thermally activated at different temperatures are shown in Figures 3.2-3.5.

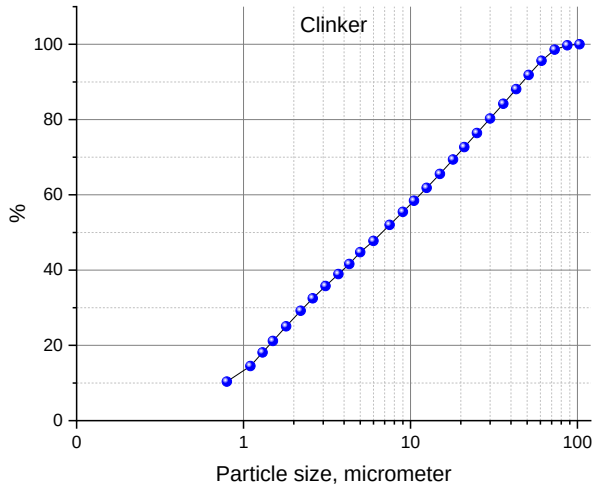

Figure 3.2 Particle size distribution graph of clinker after 60 minutes of grinding

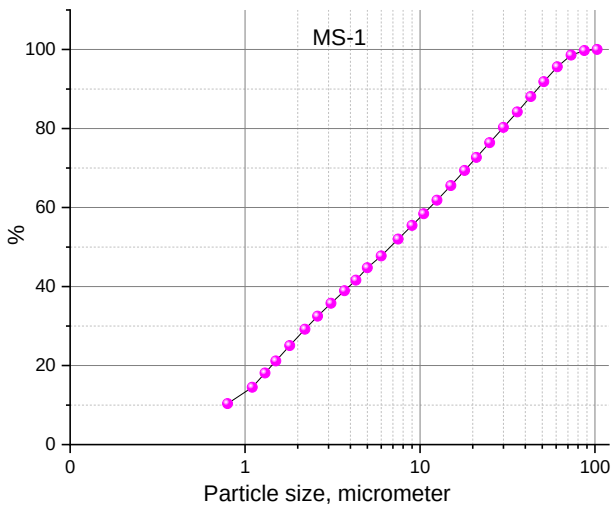

Figure 3.3 Particle size distribution graph of magnesium slag obtained at 1200-1250 ºC after 60 minutes of grinding

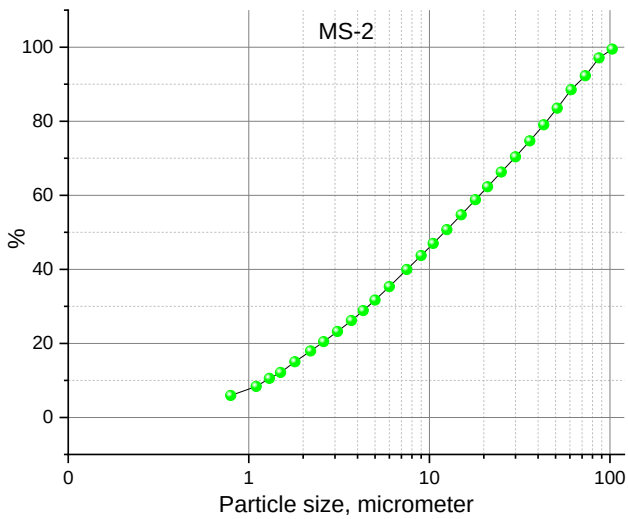

Figure 3.4 Particle size distribution graph of magnesium slag obtained at 1250-1300 ºC after 60 minutes of grinding

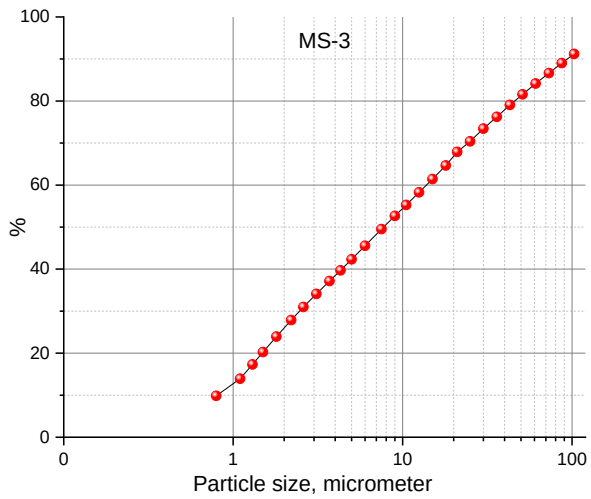

Figure 3.5 Particle size distribution graph of magnesium slag obtained at 1300-1350 ºC after 60 minutes of grinding

After 60 minutes of grinding, the most accessible material to grind was clinker. While the d_{80} of the clinker is below 30 microns, the d_{80} of the magnesium slag sample obtained at 1200-1250 ºC is below 50 microns, and the d_{80} of the magnesium slag sample obtained at 1250-1300 ºC is below 35 microns and at 1300-1350 ºC. The d_{80} of the obtained magnesium slag sample remained below 50 microns. However, the d_{97} of the magnesium slag sample obtained at 1250-1300 oC is below 136.40 microns, while the d_{97} obtained at 1300-1350 ºC is below 86.70 microns. Although the amount of clinker alite increased in the grinding of the magnesium slag sample obtained at 1250-1300 ºC, the high amount of free magnesium oxide brought about some difficulties in grinding. In the study of Tokyay and M, who investigated the effect of chemical composition on the energy consumed in grinding, 15 different types of clinker were used. According to this, Increasing the Al_2O_3 ratio causes a decrease in grinding energy. It was observed that there was a logarithmic relationship between the free lime ratio and the energy spent in grinding, and it was determined that the energy spent increased as the free lime ratio increased. The same effect was seen with increasing free MgO. A directly proportional relationship exists between specific surface area and the energy spent in grinding.

As the amount of alite in clinker increases, the work index value (kWh/ton) decreases. This shows us that the amount of energy required for grinding is decreasing. While the amount of belite in the clinker is below 20%, the energy requirement for grindability decreases with the increase in the percentage of belite. However, if the amount of belite is present at a certain level (around 22%), the grinding energy requirement increases again (Güllü, 2006). As seen from Table 3.3, clinker reveals the lowest work index, while a sample of magnesium slag formed due to thermal activation at temperatures of 1200-1250 ºC has the highest. However, when comparing a sample of magnesium slag formed as a result of thermal activation at 1200-1250 ºC and a piece of magnesium slag (MS-1) created as a result of thermal activation at 1300-1350 ºC (MS-3) temperatures diabase, the work index of MS-3 is lower than that of MS-1. As a result of the high alite content of the clinker, grindability becomes more accessible, while the high belite content makes grindability difficult. The excess of the liquid phase facilitates the grindability of the clinker. Cement behaviour can be changed by studying clinker chemistry and mineralogical phases in the clinker production process. Therefore, clinker meal energy also varies depending on the phase structure. Energy gain is achieved in meals by bringing the phase structures to the desired levels (Güllü, 2006).

Table 3.3 Wi values of cnlinker and magnesium slag samples

1400-1450 ºC/ Clinker kWh/t	1200-1250 ºC/ Outdoor Self-Cooling kWh/t	1250-1300 ºC/ Outdoor Self-Cooling kWh/t	1300-1350 ºC/ Outdoor Self-Cooling kWh/t
13,56	14,92	14,76	13,94

In studies conducted with blast furnace slag, work index values have a wide scale between 10-17 kWh/t. The work index of blast furnace iron slag varies between 12-18 kWh/t (911metallurgist, 2023; Kohitlhetse et al.,2023). Thermal magnesium slag formed at different temperatures is consistent with the results of scientific studies. As a result of thermal activation, it even approached the work index of clinker.

4. Conclusions

The amount of alite in the Portland cement cinder mineral structure is approximately 57% higher than MS-1, about 50.93% higher than MS2 and about 32% higher than MS-3, compared to the alite amounts in magnesium slag samples formed due to thermal activation. However, the increase in thermal activation of magnesium slag caused the alite phase to increase, facilitating the grindability of magnesium slag samples. However, the equal grindability of magnesium slags produced due to thermal activation lags behind that of Portland cement. The biggest reason for this is magnesium slags' high belite phase amounts. Although the free MgO contained in magnesium slags is within the standard in cement production, its high level compared to Portland cement clinker makes grinding difficult and causes an increase in energy costs.

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GREEN TRANSFORMATION IN THE CEMENT INDUSTRY: THE ROLE OF ENERGY AND INNOVATION

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ABSTRACT

In the cement sector, energy is consumed intensively and is generally based on fossil fuels. With green energy, the cement industry aims to reduce carbon emissions, optimize energy consumption and minimize concentration effects. The cement industry is undergoing a significant transformation towards industrial sustainability. This transformation includes various innovations to optimize energy consumption and reduce carbon footprint, making cement factories' energy use more efficient and environmentally friendly. Innovations such as using alternative raw materials and carbon capture and storage technologies shape the cement industry and create a sustainable road map. This paper highlights how the green transformation process of cement takes place. Green transformation is critical in developing the cement industry and contributing to global sustainability efforts. The cement industry has significantly changed within the sustainability and environmental awareness framework. This study examines the green transformation of the cement industry, focusing primarily on the role of energy use and innovation. It looks at how green energy conversion (solar, wind, hydroelectric) can be used in cement production and how energy methods can be developed. It discusses the green transformation process of the cement industry and explains the role of energy use and innovation in this process. Additionally, the assessment of cement production sustainability is designed to highlight innovations in the sector and exploit both the challenges and opportunities of green performance. Thus, by providing information on the sustainability of the cement industry, producers in the sector will be informed in the light of discussions and solution suggestions.

Keywords: Cement, Green transformation, Energy, Innovation.

1. Introductıon

In addition to being the cornerstone of modern construction, the cement sector plays a vital role in supporting industrial activities and infrastructure projects. However, the traditional production methods of this sector have brought environmental challenges such as energy intensity and carbon emissions. In this context, green transformation in cement production has become an important strategy to achieve sustainability goals and minimize environmental impacts. The point where green transformation meets energy and innovation in the cement sector brings with it essential opportunities that can provide solutions to the fundamental problems faced by the industry. Carbon emissions from facilities traditionally powered by fossil fuels are a primary environmental concern in the industry. However, integrating renewable energy sources and electrification can make cement production processes cleaner and more efficient. In addition, innovation and technological advances have brought about new approaches to increase the use of environmentally friendly materials, carbon capture technologies and energy efficiency in cement production. In this context, innovations such as zero-carbon fuels used in the cement sector, alternative raw materials and more effective production methods allow the industry to evolve towards a sustainable future (Kızıltan and Doğan).

To comply with the goals of the European Green Deal and minimize environmental impacts, essential steps are being taken in the cement industry to adopt innovative technologies, develop sustainable business models, use resources cyclically, and reduce carbon footprint. The "Green Deal Action Plan" is designed in line with the green transformation policies worldwide, especially in EU countries. This plan aims to provide a road map that encourages green investments, supports the use of green technology, and ensures a sustainable, economical, and safe energy supply in terms of energy management. The plan's focus includes moving away from the linear economy based on fossil energy sources and towards a green and circular economy. This transformation has necessitated a radical change in energy management and policies. Apart from nuclear

energy, renewable energy policies have also gained importance in this context throughout the world. Renewable energy resources are defined as unlimited and clean resources that constitute an alternative to fossil resources. The energy sector is critical in transitioning to the green and circular economy. In this process, the cement sector is one of the energy and resource-intensive sectors with high energy use and greenhouse gas emissions (İSO Yeşil Blog, 2023; TSKB, 2023).

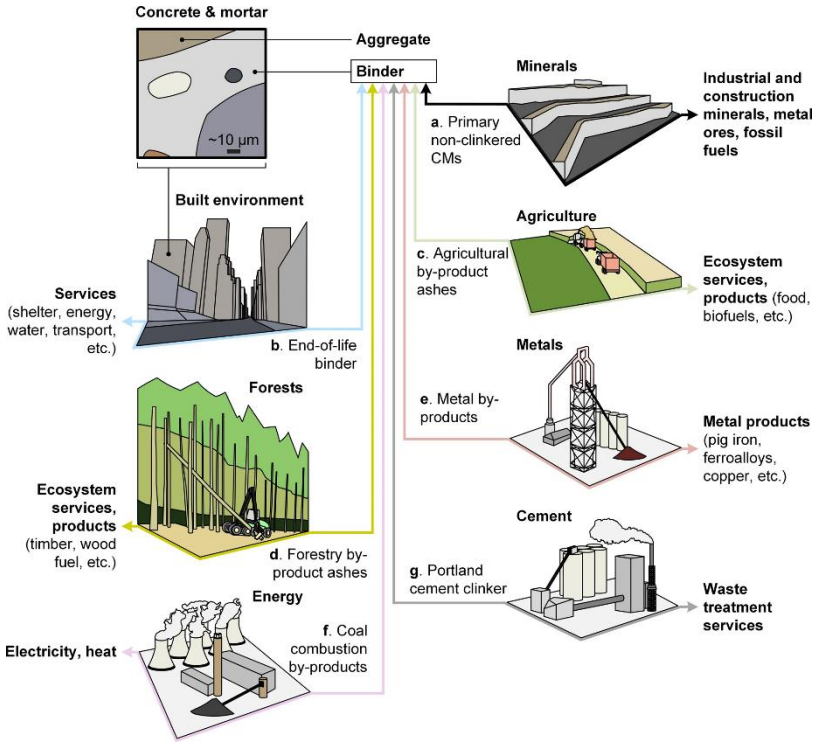

Figure 1. Substitution in the cementitious binder, and in mortar and concrete (product scale, top left), is linked in several important ways to the wider industrial system (market scale, a–g). g Clinker can be substituted by secondary cementitious materials (CMs) from the (a) minerals, (b) built environment, (c) agriculture, (d) forestry, (e) metals, and (f) energy sectors (Shah at al., 2022).

Within the framework of compliance with the Green Deal, sustainable production indicators and measurement of the cement sector, low-carbon innovative production technologies, corporate carbon footprint, transition to renewable energy sources, research for decarbonization, waste management and circular economy have become priorities. In addition, issues such as strengthening legislation and incentive mechanisms, developing qualified human resources and accelerating digitalization processes within the framework of the urgent needs required by the Green Deal come to the fore. Among the solution suggestions that come to the fore as a result of the research, include:

- Diversifying university-private sector-public collaborations.
- Developing new collaboration models.
- Providing financial support and facilities to encourage partnerships.
- Establishing institutes focused on green transformation.
- Creating an environment of trust between collaborating parties (İSO Yeşil Blog, 2023).

This paper examines the green transformation in the cement sector in detail from the perspective of energy and innovation, addressing the challenges faced by the industry and potential strategies that can address these challenges. The critical elements of the sector's transformation are the role of zero-carbon fuels, renewable

energy use, and environmentally friendly production techniques in cement production. Today, the cement industry has entered a critical turning point in its search for solutions to its environmental and sustainability challenges. Among the energy-intensive sectors, cement plays a vital role in the EU economy by operating in steel, cement and chemicals. However, these sectors need to modernize and reduce carbon emissions. Therefore, increasing the use of green energy resources globally and encouraging green investments is necessary.

2. Fuels can be Used to Achieve the Zero Carbon Target

As the world population increases, and industrialization accelerates, our energy needs increase exponentially. This makes the fight against the climate crisis more complex by increasing carbon footprints, especially in energy-intensive industries such as cement production. Traditional production processes in the cement industry impose a high environmental cost. In addition, the widespread use of fossil fuels increases greenhouse gas emissions, creating an important factor in climate change. However, the transition to zero-carbon fuels in cement production could make a revolutionary change in this sector. Integrating innovative technologies and sustainable practices into the cement industry can reduce emissions and costs by increasing energy efficiency (Yuan at al., 2023).

Green transformation is an issue specific to the cement industry and a source of inspiration for many sectors. Switching to zero-carbon fuels in cement production reduces carbon emissions and is essential to a clean, sustainable energy future. The cement industry will play an important leading role in the fight against climate change by leading other initiatives with these efforts towards a zero-carbon end. In many countries, cement producers have invested significantly in transitioning from traditional and petroleum coal to alternative fuels. The cement industry uses alternative fuels derived from waste through "co-processing, " combining material recycling and energy recovery. Currently, alternative fuels, including waste biomass, account for 44% of the cement industry's fuel mix. Within the Low Carbon Road Map framework, this rate aims to increase to 60% by 2050. In this way, a 27% reduction in fuel-related CO_2 emissions can be achieved (ECKA, 2023).

2.1 Biomass

Today, sustainability of energy demands and carbon footprint reduction push industries to seek innovative and environmentally friendly solutions. In this context, the use of biomass in energy production, especially in the cement sector, has a vital role in efforts to achieve sustainability goals. Cement production is energy-intensive and often involves extensive use of fossil fuels. In Europe, the cement industry has replaced much of its traditional fuel sources with biomass or waste. According to 2019 data, 50 per cent of alternative fuels are consumed instead of fossil fuels in EU countries. It reaches 90 per cent in some cement plants. Turkey creates approximately 12 million 702 thousand tons of usable biomass balance annually. By using local biomass balance, forest residue, bed litter and conversion waste for alternative energy purposes, the cement industry can pay less for imported fossil fuels, and energy supply security can be ensured; foreign dependency on energy and greenhouse gas CO2 emissions can be reduced, contributing to local development and improving cement facilities. Environmental pressures are minimized (Öztürk, 2022).

The use of biomass in the cement industry provides double profits. First, biomass energy can provide energy through direct combustion in cement plants. Secondly, biomass can be used as a raw material in the cement production process.

Biomass Direct Combustion; Biomass can be burned directly in cement plants to provide energy. This may include wood, pomace or vegetable waste. This method offers a sustainable option for energy production in cement kilns instead of traditional fossil fuels. Thus, it contributes to lower carbon emissions and biodiversity conservation potential than fossil fuels (Illankoon at al., 2022)

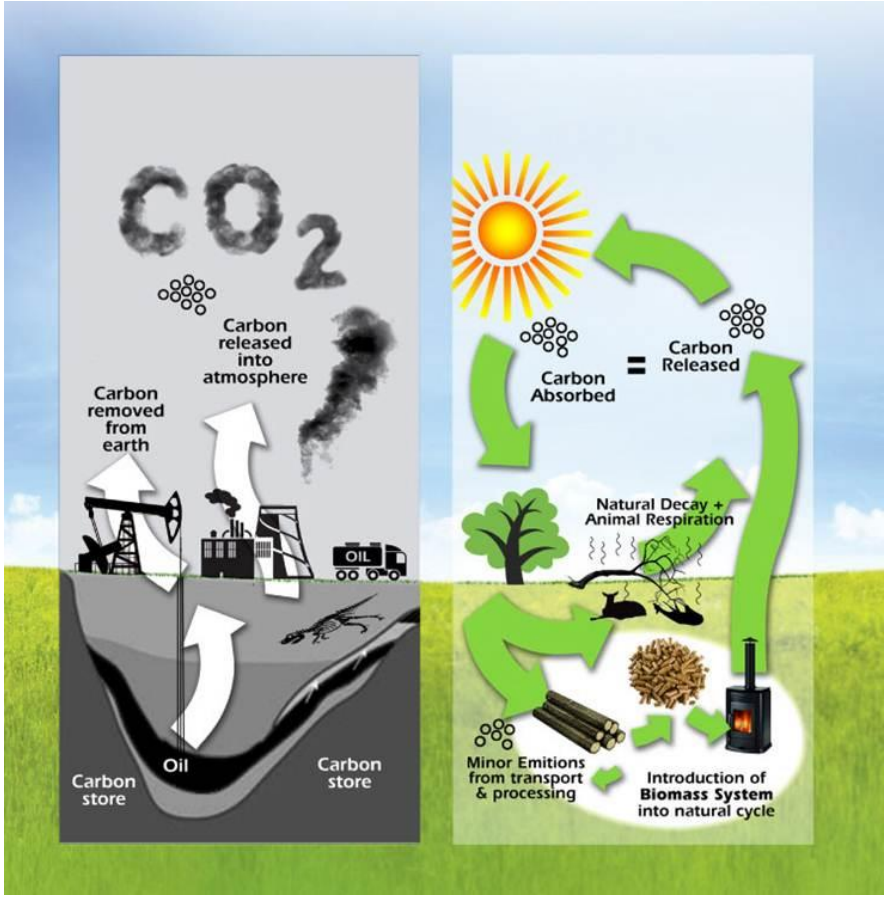

Figure 2. Biomass use cycle (Balkangreenenergynews, 2023)

Production of Bio-Derived Raw Materials: Biomass can also be used as a substitute for raw materials used in cement production. For example, bio-roots from energy crops can be used as clinker raw material in cement production. The type of biomass used by cement plants is highly variable and relies on locally grown products. For example, rice husks, corn cobs, hazelnut shells, peanut shells, peanut shells, walnut shells, bagasse, bean husks, coconut shells, cotton stalks, orange pruning waste, corn stalks, straw, and palm shells are among the many types of biomass currently burned in cement kilns (Öztürk, 2022).

2.2 Hydrogen

Access to clean energy sources and the availability of sufficient hydrogen for use by industry are among the issues that need to be addressed. Hydrogen can be used directly as an energy source in cement production processes. Using hydrogen to fuel furnaces instead of traditional fossil fuels can significantly reduce carbon emissions. In a wholly decarbonized future, in a situation where the potential of natural gas has not yet been fully used, and savings in CO2 emissions can be achieved, hydrogen is one of the gases that can partially replace natural gas in the grid. Various types of hydrogen (blue, grey, green, turquoise) are classified based on the environmental impacts of different production processes. Green hydrogen is produced using renewable electricity and can be used as a cement kiln combustion fuel without contributing to the CO2 emissions associated with conventional fuels and biomass. However, it is necessary to have sufficient renewable energy for this use and to make significant investments to convert both energy and industrial assets. It is known that in recent years, pilot-scale trials have been carried out for the use of hydrogen in the cement production process. Hydrogen can affect the physical properties of the kiln system, mass flows of the fuel, temperature profile, heat transfer and factors such as the facility's safety. Therefore, further feasibility studies are required to determine the possible effects of partial hydrogen in cement kiln systems. Hydrogen in the energy and cement sectors is essential in achieving clean energy conversion and carbon-neutral production targets. However, various factors such as technological advances, infrastructure improvements, and competitive economic advantages must be considered for wide-scale adoption. Although using hydrogen as fuel, shown as one of the

solutions to the zero carbon target, is a substantial alternative, time is needed for the solution to develop (ECKA, 2023; Nhuchhen at al., 2022; Karduri, 2023).

2.3 Electrification Methods

The materials and processes used in the cement industry are highly energy-intensive and often result in carbon emissions. However, sustainability efforts in cement production include many strategies to reduce environmental impacts and increase energy efficiency. Traditionally, fossil fuels such as coal are used in cement production. However, in line with sustainability efforts, cement factories are using alternative fuels (waste tire, oil, biomass). Additionally, efforts to obtain some of the energy used in cement production from renewable sources are increasing. Cement factories constantly carry out improvement efforts to increase energy efficiency and reduce carbon footprint. This includes strategies such as making processes more efficient, using more renewable energy sources and switching to energy-saving technologies (Sahoo and Kumar, 2022; Amran at al., 2022).

Sustainability in the cement sector includes several strategies focusing on energy efficiency, carbon reduction and environmentally friendly production processes. These strategies contribute to the cement industry operating more sustainably by reducing its environmental impact and optimizing energy consumption. As the electricity grid decarbonizes, renewable or low-carbon electricity may present a feasible but technically challenging opportunity to provide cement kiln heat in the future. The cement kiln system, operated with conventional fuels, uses a flame with a temperature of approximately 2000 °C to conduct a reaction requiring a temperature of at least 1450 °C. The oven's Essential features include the flame's length, its temperature, and how it transfers heat to the raw materials. Theoretically, carbon-free energy could be used to create electromagnetically generated plasma. Although there is no existing example of plasma technology in cement production, there are examples of plasma technology in the waste treatment sector. The industry is researching the amount of electricity needed (estimated at around 300 MWe for an average furnace), its cost, and the technical information currently required for the design of such a new furnace. Using electricity as heat input for cement production poses a significant challenge as production processes require temperatures of up to 1450°C. No solutions are available on the market, as there are no case studies yet for development in this area. Although there is no real technical obstacle, a prerequisite for using electricity for heat production in the future is that the electricity is produced 100% fossil fuel-free and sold at an affordable price (ECKA, 2023; Turk Cement, 2023).

Possible technologies being studied include:

Plasma is one of the fundamental states of matter that occurs when a gas is heated sufficiently to form an ionized gas. Temperatures between 3000 and 5000°C can be achieved. This concept involves using plasma generators in a preheater and precalcination furnace.

Electric current heaters: Heat is produced by passing current through a resistive element, usually protected by a sheath, and transferred to the gas flow by high-speed convection. Maximum gas outlet temperatures are reported to be 1100°C- 1200°C.

- Microwave heating
- Resistive electric heating
- Induction heating

Each of these technologies has the potential to replace traditional fuels in cement production and provide a more sustainable heat source. However, sustainability and cost-effectiveness of electricity generation are essential factors and studies in this area are ongoing. Electrification of any industry is a process greatly influenced by energy and environmental policies. In addition to the cost of electrification, electricity prices must also be competitive. Additionally, industry electrification can reduce greenhouse gas emissions only if renewable energy generation capacity is added. Global renewable energy generation capacity is increasing, and by 2050, more than 80% of electricity is projected to come from renewable sources (ECKA, 2023).

3. New Generation Resources in Energy Conversion

3.1. Solar energy

Solar energy is obtained through photovoltaic (PV) panels and thermal energy systems that convert the light and heat energy from the sun into electrical energy. PV panels are devices that convert sunlight directly into electrical energy. Photons in sunlight cause electrical voltage in semiconductor materials. This voltage enables electricity production in solar panels.

Thermal Energy Systems: Solar energy can also be used with thermal energy systems. Solar energy is collected through solar collectors, which heat is used to heat a fluid. The heated fluid can produce steam, which a turbine and generator can use to generate electricity.

Solar energy can be applied in various areas in the cement industry:

Electrical Energy Production: Cement production is a process that consumes high energy. Solar energy can be used to meet the electricity needs of cement factories. PV panels or thermal energy systems can help cement factories produce their electricity (Ferrario at al., 2023; Maka and Alabid, 2022).

3.2. Hydrogen Energy

Hydrogen energy has significant potential for the cement sector and general energy production. Hydrogen can replace fossil fuels used in cement factories. The cement industry is an energy-intensive sector. Therefore, using hydrogen to provide energy at high temperatures can improve energy efficiency in cement production. Using hydrogen in energy-intensive processes such as clinker production can reduce carbon emissions. Hydrogen is considered a clean energy carrier because only water and heat are released when burning or reacting with oxygen in electrochemical cells to produce energy. This reduces the environmental impacts associated with using hydrogen. Green hydrogen is created through water electrolysis using electrical power from renewable energy sources. The hydrogen produced during this process is free from carbon emissions and is a clean and sustainable energy source. However, some challenges limit the widespread use of hydrogen. The production, storage and transportation of hydrogen is energy intensive and costly. Moreover, the hydrogen economy's infrastructure still needs to be fully developed. However, with technological developments and increasing investments, hydrogen is expected to become a more important energy carrier (Nhuchhen at al., 2022; Guo at al., 2023).

3.3 Wind Energy

Wind energy is obtained from wind, which is an unlimited resource and an environmentally friendly energy source. Unlike fossil fuels, wind energy significantly reduces greenhouse gas emissions. Wind energy is a constantly renewed resource due to the sun's uneven heating of the earth's surface. This makes wind energy an inexhaustible resource. The cost of wind energy is gradually decreasing with the development of technology and economies of scale. Increasing efficiency and falling prices allow wind energy to become more competitive against other energy sources. Wind turbines generally offer economic advantages in terms of operating and maintenance costs. Modern wind turbines are usually long-lasting and have relatively low maintenance costs. Wind turbines are systems that generally operate automatically and have low maintenance. They can be put into operation and start producing energy quickly. Wind energy does not release harmful emissions into the atmosphere and has minimal environmental impact. Wind energy is obtained from wind, which is constantly occurring in nature and is an inexhaustible resource. Wind power plants can be installed quickly and take a short time to start producing energy. It plays a vital role in diversifying worldwide energy production and creating a sustainable energy future.

Wind energy is obtained by converting the kinetic energy resulting from air movements in the atmosphere into electrical power. This process is usually carried out through wind turbines. Wind turbines convert the kinetic energy of the wind into mechanical energy with their rotating blades and then convert it into electrical energy with the help of a generator. The applicability of wind energy in the cement industry has gained importance with the increasing demand for environmentally friendly and sustainable energy sources. Wind turbines can be used to meet the energy needs of cement factories. Factories can produce electricity using wind energy to meet their own energy needs. Wind energy is more environmentally friendly than traditional energy sources

commonly used in cement production. This allows cement manufacturers to reduce their environmental impact through green energy. Wind energy can reduce energy costs in the long term, making energy supply independent of cement producers. This may provide resistance to fluctuations in energy prices. Payback periods for wind energy investment may vary depending on technological developments and local energy conditions. However, it can generally be an economical option for the cement industry from a long-term perspective. Society typically receives Wind energy projects more positively because they have less environmental impact. Cement factories can contribute to social and environmental sustainability goals through environmentally friendly energy production. Cement production is an energy-intensive process and requires large amounts of energy. Therefore, wind energy applications in the cement sector must be carefully planned considering the local energy infrastructure, cost factors and technical difficulties.

3.4. Geothermal

Geothermal energy is renewable energy obtained by extracting and using hot water and steam from underground to the surface. This energy source could provide potential for various applications in the cement industry. Electricity production from geothermal sources: Hot water and steam from geothermal sources are used by a geothermal power plant and converted into electrical energy. High-temperature geothermal resources turn turbines and run generators in this system, producing electrical energy.

Cement factories often consume large amounts of energy. Geothermal energy can generate electricity through steam and turbine systems to meet the energy needs used in cement production. Geothermal energy can reduce energy costs used in the cement production process. Geothermal energy can be a stable and low-cost option, especially since cement factories need a constant energy source. It is more environmentally friendly than other energy sources used in cement production. It can reduce carbon emissions and contribute to the cement industry's sustainability goals.

Geothermal energy can also be used in heating and cooling systems in cement factories. Heat can be met with hot water and steam from geothermal resources. Geothermal facilities generally have a low carbon footprint and support environmental sustainability. However, the applicability of geothermal energy in the cement industry may vary depending on factors such as the local availability of geothermal resources and their suitability for the energy needs of cement factories. Cement production processes can be integrated in various ways depending on the local geothermal potential.

As it is known, geothermal energy is a local underground resource that is renewable, clean, cheap and environmentally friendly. Since our country is located on an active tectonic belt due to its geological and geographical location, it is in a wealthy position among the world's nations regarding geothermal resources. There are approximately 1,000 geothermal resources in natural outlets spread throughout our country at different temperatures (TUBA, 2023; MTA, 2023).

Turkey's geothermal potential is primarily concentrated in Western Anatolia, Central Anatolia, Marmara, and Eastern Anatolia. The country's position in electricity production from geothermal resources ranks fourth in the world. According to the map showing the distribution of geothermal resources, most of the areas forming the potential are located in Western Anatolia. Geothermal resources are in two main categories: low and medium temperature. These resources can be used for direct applications (heating, thermal tourism, various industrial applications, etc.) or indirect applications (electrical energy production).

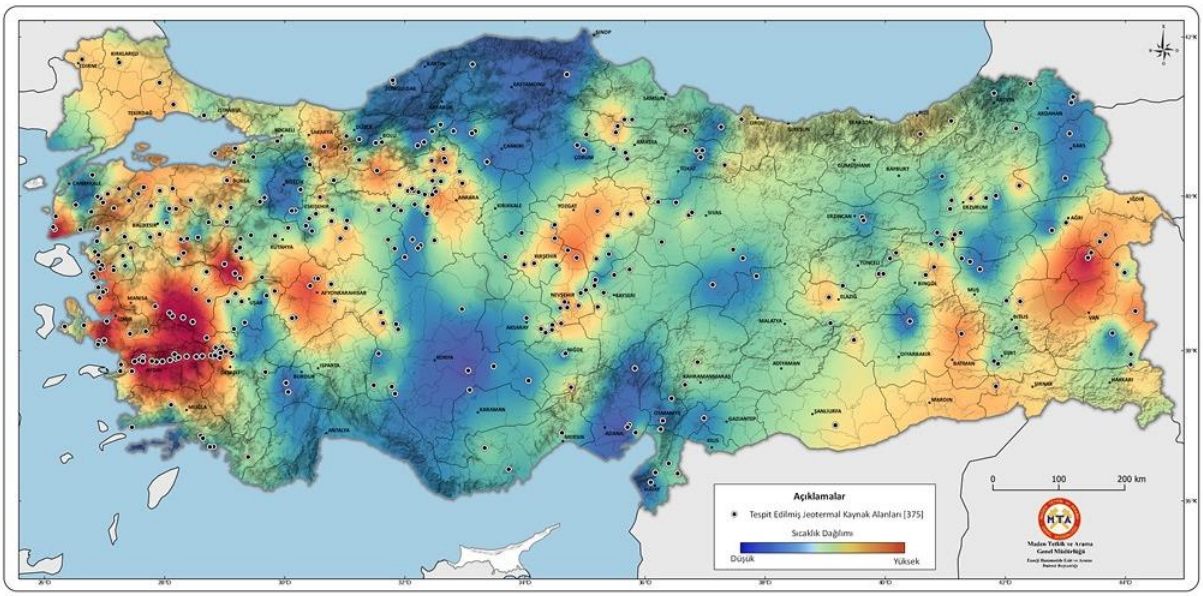

Figure 3. Turkey geothermal resource areas and temperature distribution map (MTA, 2023)

Geothermal energy applications started in Turkey in 1975, and their use for electricity generation began with projects such as the Kızıldere Power Plant. Turkey's leading position in this field meets energy needs and supports environmental sustainability. Using geothermal energy in heating, thermal tourism, industrial applications, and electricity generation increases energy diversity and ensures more effective use of resources (MTA, 2023).

4. Results

Today, increasing energy demand and global problems such as the climate crisis reveal the need for sustainable and environmentally friendly energy sources. Turkey's potential in this field and its interest in energy projects represent a promising development in the transition to sustainable energy. In this context, innovative technologies and sustainable energy sources used in the cement sector have significant potential in line with the sector's goals of reducing carbon emissions, increasing energy efficiency and minimizing environmental impacts. Renewable resources such as wind, solar, hydrogen, and geothermal energy can contribute to constructing a more sustainable and environmentally friendly future in cement production processes. However, these technologies' feasibility and economic effectiveness must be constantly reviewed to evaluate their transformation in the sector.

Green transformation in the cement industry is an essential journey at the intersection of energy and innovation. The sector must turn to radical changes to overcome the environmental challenges brought by traditional production methods and achieve sustainability goals. In this context, adopting zero-carbon fuels, renewable energy and environmentally friendly production techniques offers the potential to reduce carbon emissions in cement production processes. Additionally, innovation and technological advances can move the industry to a more sustainable future by bringing solutions such as diversifying materials used in cement production and carbon capture technologies.

As a result, green transformation efforts in the cement industry will be possible by adopting energy efficiency, environmentally friendly production and zero-carbon technologies. This transformation will ensure the sustainable evolution of the sector, reducing environmental impacts and leaving a clean cement industry to future generations.

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MICROGRID ADVISOR YAZILIMI İLE MİKRO ŞEBEKELERDE ENERJİ OPTİMİZASYONU

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ÖZET

Son yıllarda yaşanan enerji krizlerini de göz önüne aldığımızda ülkelerin kendi enerji ihtiyacının hiç de azımsanmayacak bir kısmını ana şebekeden bağımsız, kesintisiz ve yenilenebilir kaynaklardan karşılamayı planladıkları bir gerçektir. Bu konudaki ana motivasyonları daha ucuz enerji maliyetleri, kesintisiz enerji ve sürdürülebilirliktir. Bununla beraber tüm enerji ihtiyacımızı yenilenebilir kaynaklarından karşılayamasak da 'grid-tied' (şebeke ile entegre) veya 'Island-able' (ada modeli) mikro şebeke yapıları ile geleneksel enerji kaynaklarımızı çeşitlendirip optimize etmek mümkündür. Daha ucuz, sürdürülebilir ve dirençli elektrik altyapısına sahip yazılım destekli mikro şebekeler ile konutların, kurumların ve hatta devletlerin enerji ihtiyaçlarının karşılanması mümkündür. Mikro şebekeler, tüm saha işlemlerinde birbiri ile iletişim kuran ve internete açılarak bulut katmanına çıkabilen bağlanabilir niteliklere sahip cihazların kullanılması ile oluşturulur. Oluşturulan şebeke dağıtılmış enerji kaynaklarının tamamından uluslararası protokoller vasıtasıyla nokta bazlı veriler toplar. Alınan tüm veriler PLC'ler gibi saha cihazlarında toplanır. Toplanan veriler buluta çıkabilen bir kontrol cihazı üzerinden bu alana özel olarak geliştirilmiş, makine öğrenmesi gibi yetkin karar algoritmalarını destekleyen 'Akıllı Mikro Şebeke Yazılım'ına aktarılır. Buradan dağıtılmış enerji kaynakları arasında sisteme entegre SCADA desteği ile operasyonel olarak yönlendirmeler, otopilot modunda çalışma modeli veya gelişmiş izleme ve tahmin yöntemi ile çıktılar takip edilir. Yazılım, üretilen ve tüketilen enerjinin herhangi bir 't' anında en verimli şekilde kullanılması için binlerce senaryo arasından en doğruyu seçer ve buna göre yönlendirme yapar. Bunu yaparken tüketilen enerjinin mümkün olduğunca yenilenebilir kaynaklardan sağlanması, ucuz olarak tüketilmesi ve enerjinin sürekliliği esas alınır. Bu bağlamda kaynakların yönlendirilmesinde elektrik tarife ücretinin durumu da göz önünde bulundurulur. Ayrıca karar sürecinde veri tabanında tutulan istatiksel veriler ve hava tahmini gibi çevresel koşullara ait veriler kullanılarak geleceğe yönelik %98'in üzerinde doğruluk payı ile tahminler yapılabilir. Yazılım destekli kararlı mikro şebeke modeli ile enerji taleplerinin yüksek kaliteli, kesintisiz ve verimli bir şekilde karşılanması olanaklı hale gelmektedir. Yapılan bu çalışma modeli ile mikro-şebeke mimarileri, bileşenleri ve Schneider Electric tarafından geliştirilerek piyasa sunulan Microgrid Advisor yazılımın kullanım olanaklarının incelemesi yapılmıştır. Çalışma kapsamında bir Demo uygulama ile şebeke yönetimi yazılımının sunduğu saha çözümleri uygulamalı olarak gözlemlenmiştir.

Anahtar Kelimeler: Mikrogrid, Şebeke Optimizasyonu, SCADA, Microgrid Advisor

ENERGY OPTIMIZATION IN MICROGRIDS WITH MICROGRID ADVISOR SOFTWARE

ABSTRACT

Considering the energy crises experienced in recent years, it is a fact that countries plan to meet a significant part of their energy needs from uninterrupted and renewable sources independent of the main grid. Their main motivations in this regard are cheaper energy costs, uninterrupted energy and sustainability. However, even if we cannot meet all our energy needs from renewable sources, it is possible to diversify and optimize our traditional energy sources with 'grid-tied' (integrated with the grid) or 'Island-able' (island model) microgrid structures. It is possible to meet the energy needs of residences, institutions and even governments with software-supported microgrids with cheaper, sustainable and resilient electrical infrastructure. Microgrids are

created by using connectable devices that communicate with each other in all field operations and can be accessed to the cloud layer by opening to the internet. The created network collects point-based data from all distributed energy resources through international protocols. All received data is collected in field devices such as PLCs. The collected data is transferred to the 'Smart Micro Grid Software', which has been developed specifically for this field and supports competent decision algorithms such as machine learning, through a control device that can go to the cloud. From here, the outputs are monitored through operational guidance, operating model in autopilot mode or advanced monitoring and forecasting method among distributed energy sources with SCADA support integrated into the system. The software selects the most correct scenario among thousands of scenarios to ensure that the energy produced and consumed is used in the most efficient way at any time 't' and directs accordingly. In doing so, the basis is to ensure that the energy consumed is sourced from renewable sources as much as possible, that it is consumed cheaply, and that the continuity of the energy is ensured. In this context, the status of the electricity tariff fee is also taken into consideration when directing resources. In addition, predictions for the future can be made with an accuracy of over 98% by using statistical data kept in the database and data on environmental conditions such as weather forecasts during the decision-making process. With the software-supported stable microgrid model, it becomes possible to meet energy demands in a high-quality, uninterrupted and efficient manner.

In this study, microgrid architectures, components and usage possibilities of Microgrid Advisor software developed and marketed by Schneider Electric were examined. Within the scope of the study, field solutions offered by the network management software were observed in practice with a demo application.

Keywords: Microgrid, Grid Optimization, SCADA, Microgrid Advisor

Giriş

Artan enerji maliyetleri ve sürdürülebilirlik hedeflerine ulaşma arzusu dolayısıyla dünya genelinde enerji ihtiyacı mikro şebeke olarak adlandırılan yeni enerji alanları kurularak oluşturulmaktadır. Teknoloji odaklı oluşturulan bu mikro şebekelerden enerji ihtiyacını karşılamak ucuz ve verimli bir metot olduğundan tercih edilmektedir. Dünya genelinde mikro şebekelere yapılan yatırımların giderek artacağı ön görülmektedir. Yapılan bu yatırımların birçok avantaj sağladığı gibi şebeke yönetimi ve güvenlik konularında problemleri de beraberinde getirmektedir. Çok sayıda kontrol noktası içeren mikro şebekelerde sistemin verimli çalışması enerji sağlayıcı kaynakların doğru kullanılarak kullanıcılara yüksek kaliteli ve ekonomik enerjinin sunulmasına bağlıdır. Bu da mikro şebeke dinamiklerinin makine öğrenmesi gibi yeni nesil kontrol algoritmaları ile yönetilmesi ile aşılabilmektedir.

Mikro şebekeler enerji kullanımı, enerji kaynağının çeşitliliği ve kullanıcı sayısına göre farklı ölçeklerde olabilen lokal olarak bölgede faaliyet gösteren yenilenebilir enerji sistemleri ve santraller gibi dağıtılmış enerji kaynaklarından (DER) beslenebilen, enerjiyi depolayabilen ve gerektiğinde enerji arzını karşılamak için bu enerjiyi kullanabilen, bağımsız çalışabilen elektronik temelli akıllı elektrik şebekeleridir. Enerji arzında sürdürülebilir ayak izini ve dayanıklılığı artırırken DER yapılarını birbirine bağlayan, izleyen ve kontrol eden sistemlerdir. Ana güç şebekesine bağlı veya bağlantısı kesilmiş "ada modu" çalışabilen mikro şebekeler, düşük enerji seviyesi, aşırı enerji arzı ve yüksek enerji tarifleri gibi durumlarda şebeke dinamiklerinin en iyi şekilde yöneterek enerji kesintisi ve voltaj düşümü gibi olası enerjinin kalitesinde düşüş ya da çok yüksek maliyetli enerji kullanımı problemlerinin önüne geçebilmektedir (Enerji Portalı, 2023).

Mikro şebekelerde enerji taşınması kaynaklı enerji kayıplarının en aza indirilmesi ve bölgenin enerji ihtiyacını kendi kendine karşılaması amacı ile elektrik DER yapıları tüketim noktalarına yakın konumlandırılmaktadır. Dolayısı ile merkezi bir elektrik santralinde elektrik üreten ve daha sonra bunu yüzlerce kilometrelik iletim hatlarına dağıtan geleneksel elektrik şebekesinden farklı olarak, bir mikro şebekelerde elektriğin üretildiği bölgede kullanımı söz konusudur. Elektrik üretiminde mikro şebekenin yapısına göre karbon içerikli yakıtlarla çalışan jeneratörler ya da güneş enerji sistemi (GES), rüzgar enerji sistemi (RES) gibi yenilenebilir enerji sistemlerinin (YES) kombinasyonları kullanılabilirken, YES tarafından sağlanan ya da ihtiyaca göre düşük tarife ile satın alınan elektrik batarya ünitelerine depolanabilmektedir. Depolanan bu düşük maliyetli elektrik talep artışı ya da elektrik kesintisi gibi istenmeyen durumlarda akıllı kontrol algoritmaları kontrolünde şebekeye tekrar aktarılmaktadır. Dolayı ile mikro şebekeler mevcut kaynakların sağladığı enerji miktarı, enerji talep oranı gibi dinamiklere bağlı olarak ana şebekeye bağlı, kısmen bağlı (ada modeli) ve bağımsız olarak üç farklı modda çalışabilmektedir (Çizelge 1).

Çizelge 1. Ana kaynak bakımından mikro şebeke mimarileri

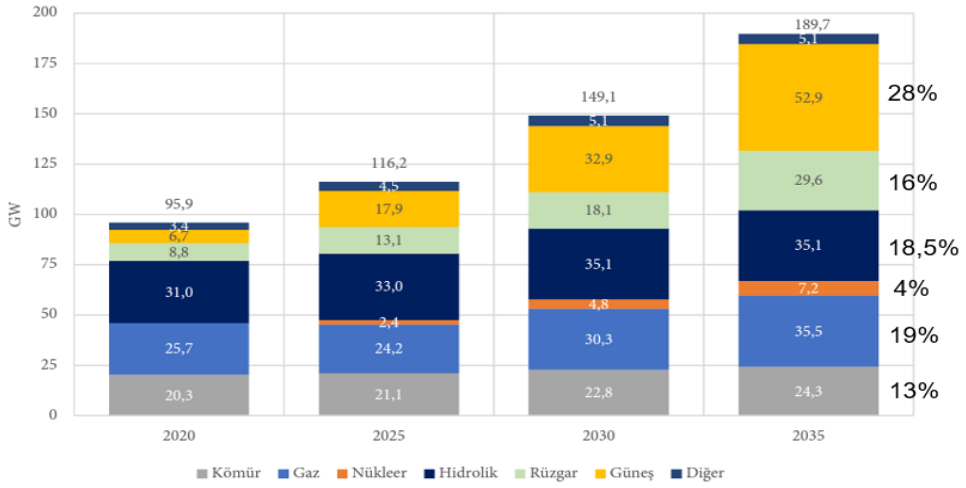
ANA ŞEBEKE İLE BAĞLI		• **İhtiyaç duyulan elektrik büyük oranda ana şebeke üzerinden sağlanmaktadır.** • **Bölgesel saha problemlerinden etkilenmeyen bu çalışma modunda enerji piyasasındaki dalgalanmalar, küresel sorunlar doğrudan şebekeye etki eder.** • **Geniş bir dağıtım ağının kontrolü söz konusudur.** • **Bölgesel problemlerin tespiti ve çözüm süresi uzun sürer.** • **Ana şebekede elektrik kesintisi meydana gelmesi durumunda bu durumdan tüm ağlar etkilenir.**
ADA MODELİ		• Hibrit bir çalışma modelidir. Ana şebekeden bölgede üretilen enerji yetersiz olduğunda elektrik çekilir. • Bununla beraber talep edilen enerjinin öz tüketimden karşılanması esastır. • Kısıtlı bir alanda etkili olduğu için şebeke yükü ile mevcut kaynakların düzenli takibi ve yönlendirilmesini yapmak daha kolaydır. • Diğer bir yandan mikro şebeke gerilimi ve frekansının aana şebeke ile uyumluluğunun sürekli kontrol edilmesi gerekmektedir.
ANA ŞEBEKEDEN BAĞIMSIZ		• Ana şebekeden bağımısız çalışma söz konusudur. • Enerjinin üretildiği bölgede tüketilmesi prensibine dayanır. • Küresel sorunlar, politik etkiler ya da enerji piyasalarındaki dalgalanmalarından doğrudan etkilenmez. • Mevcut kaynakların izlenmesi ve kontrolü çok daha kolaydır. • Yerel kaynakların talebi karşımaması riski her daim mevcuttur.

Yapılan bu çalışma modeli ile mikro-şebeke mimarileri, bileşenleri ve Schneider Electric tarafından geliştirilerek piyasa sunulan Microgrid Advisor yazılımın kullanım olanaklarının incelemesi yapılmıştır. Çalışma kapsamında bir Demo uygulama ile şebeke yönetimi yazılımının sunduğu saha çözümleri uygulamalı olarak gözlemlenmiştir.

Türkiye'de Mikro Şebekelere ve Yenilenebilir Enerjiye Genel Bakış

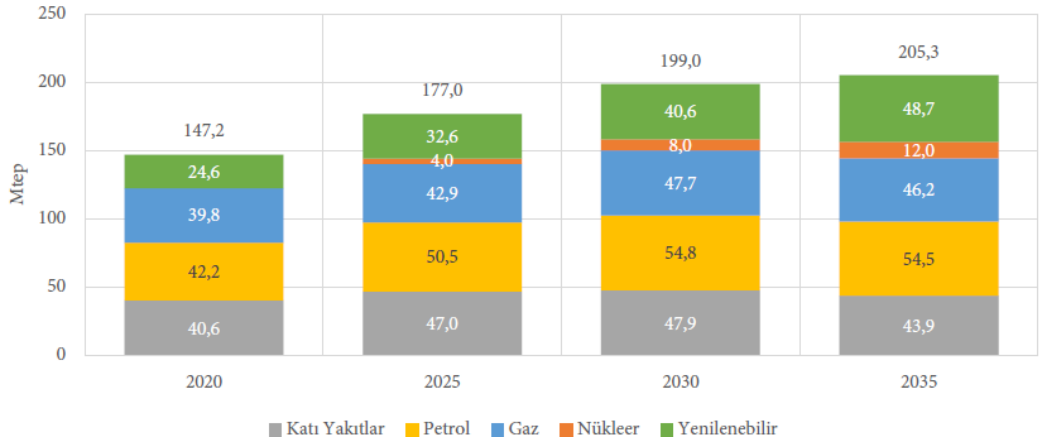
Mikro Şebekeler ve RES, enerji verimliliği ile birlikte Türkiye'nin artan enerji ihtiyacının sürdürülebilir koşullarda sağlanabilmesi ve gelişen enerji sisteminin güvenli ve temiz enerji geleceği için en kritik faktörlerdendir. Geçtiğimiz otuz yıl içerisinde aylar bazında enerji dağılımı önemli değişkenlik göstermiş olmakla birlikte YES'lerin elektrik üretimine katkısının genel olarak 35% - 45% seviyesinde olduğu görülmüştür (Yenilenebilir Enerji Portalı, 2023). Bu bağlamda Türkiye'nin YES ve ilgili teknolojilerde, enerji güvenliği, temiz enerji dönüşümü, rekabetçi ve teknoloji odaklı sanayi gelişimi için çok boyutlu fırsatlar sunan yüksek büyüme potansiyelinin değerlendirilmesi için elektrik sisteminin omurgasını oluşturan şebekelerin kapasitesinin ve esnekliğinin, uzun vadeli dinamik planlama ile desteklenen teknoloji odaklı yatırımlar ile güçlendirilmesi gerekli olduğu oldukça açıktır. Çizelge 2'de Enerji ve Tabii Kaynaklar Bakanlığı verilerinde 2035 yılında ulaşılmak istenen YES kurulu gücü hedefleri görülmektedir. Grafikten de anlaşılacağı gibi Türkiye'nin halihazırdaki elektrik sisteminde sahip olduğu ve önümüzdeki dönemde sahip olabileceği esneklik imkanları ve yenilenebilir enerji potansiyeli dikkate alınarak, rüzgar ve güneş gibi kesintili yenilenebilir enerji kaynaklarının toplam elektrik üretimi içindeki paylarının yükseltilmesi ön görülmektedir. Bu doğrultuda 2035 yılında YES tipine göre kurulu gücün, güneş enerjisinde 52,9 GW, hidroelektrik santrallerde 35,1 GW, rüzgar enerjisinde 29,6 GW (24,6 GW kara, 5 GW deniz, jeotermal ve biyokütle enerji santrallerinde ise toplam 5,1 GW seviyesine kadar yükselmesi hedeflenmektedir (Ulusal Enerji Planı Portalı, 2023).

Çizelge 2. 2035 yılı yenilenebilir enerji hedefleri (Ulusal Enerji Portalı, 2023)



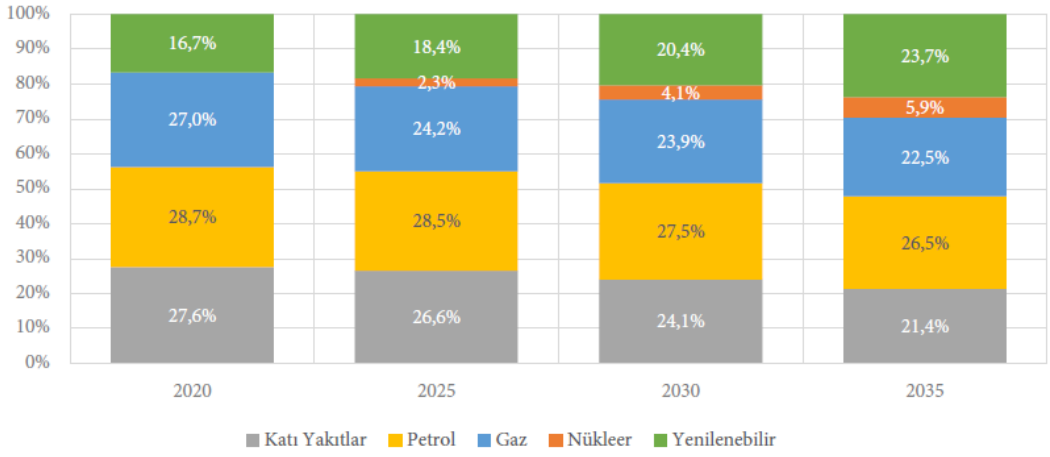
Ülkemizin 2020 yılı birincil enerji tüketimi Çizelge 3'te de görüldüğü üzere 147,2 Mtep olarak gerçekleşmiştir. İlgili grafikte de görüldüğü gibi 2035 yılına kadar birincil enerji tüketiminin 205,3 Mtep'e yükselmesi ön görülmektedir. Yine tahminlere göre 2000-2020 döneminde yıllık ortalama %3,1 oranında artış göstermiş olan birincil enerji tüketimi, 2020-2035 döneminde %2,2 düzeyinde artmaktadır. Ayrıca 2020 yılında 1,7 tep/kişi olan kişi başı birincil enerji tüketimi 2,1 tep/kişi düzeyine çıkmaktadır. 2020 yılında %16,7 olan birincil enerji tüketimi içindeki YES payı 2035 yılına kadar %23,7 bandına yükselmektedir. Nükleer enerji ise 2035 yılına kadar %5,9'luk paya ulaşmaktadır. 2020 yılında %83,3 olan fosil kaynakların payı 2035 yılına kadar %70,4 olarak gerçekleşmektedir. Kömürün payı %21,4'e inerken, petrol %26,5, doğal gaz %22,5'e gerilemektedir.

Çizelge 3. Kaynaklara göre birincil enerji tüketimi



Çizelge 3 ve Çizelge 4'te sunulan verilere göre; 2020 yılında elektrik üretiminde %11,7 orana sahip olan kesintili YES payı, 2035 yılına kadar kademeli olarak %34,3'e kadar yükselmektedir. Benzer şekilde, 2020 yılında elektrik üretiminde %42,4 olan YES payı 2035 yılına kadar %54,8'e çıkmaktadır.

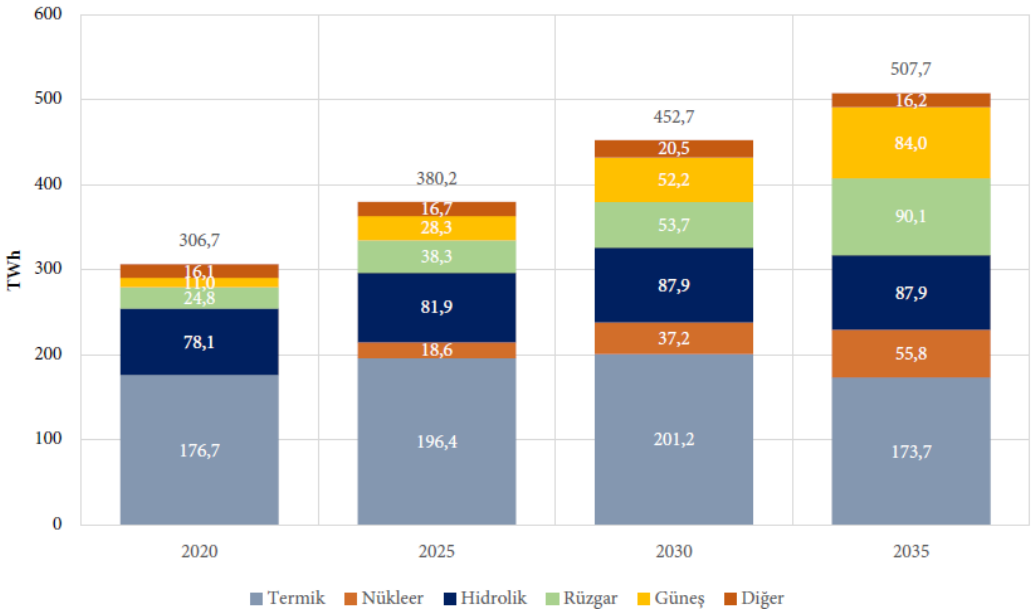
Çizelge 4. Kaynaklara göre birincil enerji tüketiminin dağılımı



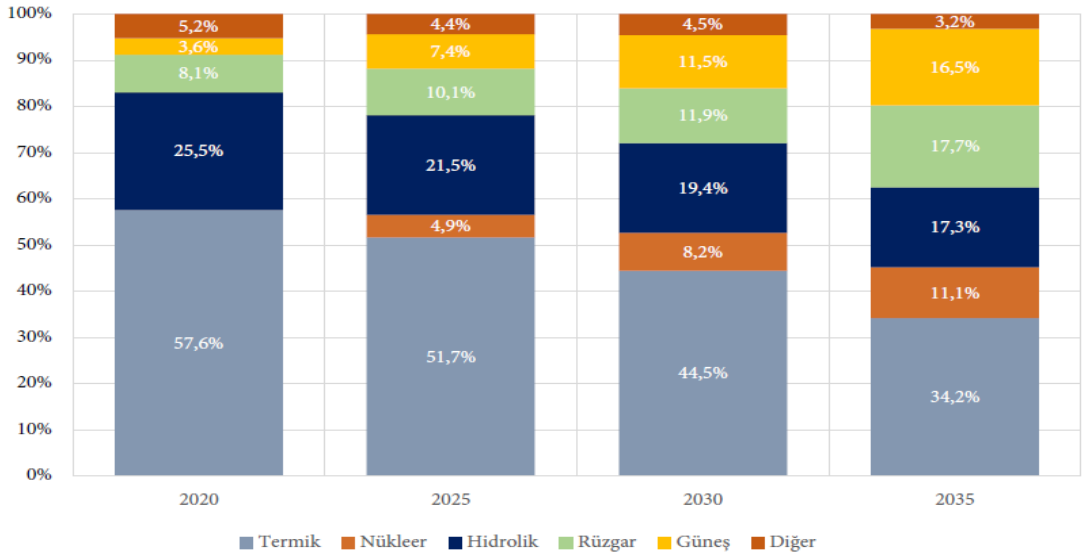
Mevcut durumda kurulu güç içinde en fazla paya sahip olan hidroelektrik santrallerin payı, maksimum kurulu güç potansiyeline yaklaşmış olmalarının ve toplam elektrik üretimindeki artışın etkisiyle 2035 yılında %17,3 olmaktadır.

Doğal gaz santralleri, diğer kaynaklardan gerçekleşen elektrik üretimindeki olası değişkenlikleri dengelediği için, dönemsel olarak sonuçlarda gösterilen değerlerden daha yüksek ya da düşük katkı sağlayabilmektedir. 2020 yılında üretimde %34,5 paya sahip olan kömür santrallerinden sağlanan elektrik üretimi 2035 yılına kadar azalarak devam etmektedir (Çizelge 5 ve 6). Kömür santrallerinin elektrik üretimindeki rolü üstünde, elektrik ve ısı üretim sektörü için geçerli olacak karbon fiyatlarının belirleyici rol oynaması beklenmektedir. Bununla birlikte, elektrik arz güvenliğini teminen baz/esnek yük santrallerine uygulanan kapasite destekleme mekanizmasının ulusal hedef planı döneminde devam etmesi öngörülmektedir (Yenilenebilir Enerji Görünümü Portalı, 2023).

Çizelge 5. Kaynaklar bazında elektrik üretimi



Çizelge 6. Kaynaklar bazında elektrik üretiminin dağılımı



Ayrıca, 2035 yılına kadar olan dönemde karbon yakalama teknolojisine sahip yeni bir kömür ya da doğal gaz santrali için yatırım kararı alınmadığı görülmektedir. Bununla birlikte, teknolojik gelişmelere bağlı olarak fiyatlardaki düşüşün hızlanması ile kömürün elektrik üretimine bu çalışmada yer alan sonuçlardan daha yüksek bir katkı sağlaması da olası görünmektedir.

Türkiye'de mikro şebekeleri oluşturan iki ana üretici grup bulunmaktadır. Bunlar;

Lisanssız Üreticiler: Elektrik üretiminde lisanssız üreticiler, genellikle yenilenebilir enerji kaynaklarından elektrik üreten küçük ölçekli üreticileri ifade eder. Bu kişiler veya şirketler, geleneksel büyük ölçekli enerji üreticilerine kıyasla daha küçük boyutlarda çalışır ve genellikle dağıtık enerji üretim sistemleri olarak adlandırılan yapılarla ilişkilendirilirler. Lisanssız elektrik üreticileri genellikle güneş enerjisi, rüzgar enerjisi, hidroelektrik enerji, biyokütle veya mikrohidroelektrik gibi yenilenebilir enerji kaynaklarını kullanarak elektrik üretirler. Bu tür üretim yöntemleri genellikle çevre dostu ve sürdürülebilir enerji üretimini teşvik etmeyi amaçlar. Lisanssız elektrik üretimi, enerji sektöründe çeşitliliği teşvik edebilir, enerji verimliliğini artırabilir ve enerji güvenliği sağlayabilir potansiyele sahiptir. Bununla birlikte, bu tür üreticilerin enerji sistemine entegrasyonu ve yönetimi, teknik ve yasal zorluklar ortaya çıkarabilir. Bu nedenle, lisanssız elektrik üretimiyle ilgili düzenlemeler, güvenliğin sağlanması ve tüm paydaşların çıkarlarının korunması için önemlidir.

Resmi verilere göre, 2020 yılının ilk 9 ayında toplam elektrik üretiminin %1,9'u lisanssız üretim tesislerinden karşılanmış olup Eylül 2020 sonu itibariyle toplam kurulu güç 6.548 MW olarak gerçekleşmiştir. Çizelge 7'de detaylı kurulu güç bilgileri yer almaktadır.

Çizelge 7. 2020 yılı lisanssız üreticiler kurulu güç dağılımı

KAYNAK TÜRÜ	KURULU GÜÇ (MW)	ORAN (%)
GÜNEŞ	6.036,80	92,20
DOĞAL GAZ	354,31	5,41
BİYOKÜTLE	77,23	1,18
RÜZGÂR	70,83	1,08
HİDROLİK	8,65	0,13
TOPLAM	**6.547,81**	**100,00**

Lisanslı Üreticiler: Elektrik enerjisi üretimi için gerekli izin ve lisanslara sahip olan şirketleri veya kuruluşları ifade etmektedir. Bu üreticiler, genellikle büyük ölçekli enerji şirketleri veya kamu kuruluşlarıdır. Lisanslı üreticiler, genellikle enerji düzenleyici kurumlar veya hükümetler tarafından düzenlenir ve denetlenir (6446

sayılı EPK Elektrik Piyasası Kanunu). Bu düzenlemeler, enerji üretiminin çevresel ve güvenlik standartlara uygun olarak gerçekleştirilmesini sağlar. Lisanslı üreticiler, enerji sektöründe büyük bir rol oynarlar ve genellikle ulusal enerji politikalarının uygulanmasında etkili olurlar. Lisanslı üretici olarak piyasada faaliyet göstermek isteyen ve kurulu gücü 5 MW'ın üzerinde YES ile elektrik üretimi yapmak isteyen yatırımcılar Enerji Piyasası Düzenleme Kurumun (EPDK)'dan üretim lisansı almak zorundadır.

Mikro Şebekeyi Oluşturan Üretim Kaynakları, Tüketiciler ve Yükler

Mikro şebeke, yerel olarak enerji üretimi, depolama ve tüketimi için optimize edilmiş bir enerji sistemidir. Bu sistemde, farklı üretim kaynakları kullanılabilir. Genel olarak Mikro şebekeleri oluşturan üretim kaynakları, RES, GES, Mikro hidroelektrik santraller, yakıt hücreleri, doğal gaz çevrim ve termik santralleri, dalga enerji santralleri, biyokütle santralleri, jeotermal santralleri, enerji depolama sistemleri, süper kapasitörler, süper iletkenler, volanlar, manyetik enerji depolama, uçan tekerlekler ve elektrokimyasal pillerdir. Ana güç şebekesine bağlı olarak çalışan ikincil enerji kaynakları, bu kaynaklara ek olarak enerji depolama sistemleri ve tüketici konumdaki yükler incelenebilmektedir.

Mikro Şebekelerin faydaları

Mikro şebekelerin birçok faydası olmasıyla birlikte, alınan faydanın miktarı ve çeşidi bölgesel olarak ya da kullanıcı tipine göre de çeşitlilik göstermektedir. Bununla birlikte tüm pazarlara yönelik sağlanan faydalar aşağıdaki gibi 3 ana başlık altında özetlenmiştir. Bunlar,

1. Rüzgar ve güneş gibi tesis içi yenilenebilir enerji kaynaklarını entegre ederek daha yeşil operasyonlara olanak sağlamaktadır.
2. Talebi optimize ederek, elektriği depolayarak ve yoğun talep sırasında şebekeye geri satarak enerji giderlerinden tasarruf edilmesini sağlamaktadır.
3. Güvenilirliği arttırarak şebeke kesintileri sırasında tesislerin gücü açık tutulabilir ve enerji ihtiyacı kesintisiz olarak sağlanmaktadır (Baran, 2017).

Sürekli gelişim ve değişim gösteren enerji gereklilikleri teknolojik gelişmeler içinde itici güç oluşturmaktadır. Bu bağlamda geleceğin enerji dağıtım ağı omurgasını daha fazla YES'e dayalı, elektrifikasyonu artan, dağıtık ve digital enerji sistemlerinden oluşan elektrik şebekelerinin oluşturacağı oldukça açıktır. Özellikle RES ve GES kapasitelerindeki güçlü büyüme kesintili üretimi elektrik sisteminin en temel unsurlarından birisi durumuna getirecektir. Talep yönetiminde etkin mekanizmaların işleyişini, mevcut esneklik seçeneklerinden daha fazla faydalanmayı, özellikle batarya depolama sistemlerinde ve destekleyici diğer depolama çözümlerinde ticari uygulama fırsatlarında artışı gerektiren bu kritik dönüşüm, şebekelerde sürdürülebilir yatırım zemininin güçlendirilmesi ile sağlanabilmektedir. Fayda oranının arttırılması açısından kurulan mikro şebekelerin dağıtılmış enerji kaynakları yazılım ile beraber optimize edilmesi, bu yolla en doğru ve verimli şekilde çalışması kritik önem taşımaktadır. Çalışmanın sonraki bölümünde mikro şebeke mimarileri, omurgayı oluşturan önemli bileşenleri ve ayrıca kullanılan yazılım uygulamaları ile ilgili detaylara yer verilmiştir.

Mikro Şebeke Mimari Yapısı ve Bileşenleri

Dağıtık üretim tesisleri, enerji üretiminin merkezi büyük santrallerden ziyade dağıtık bir şekilde gerçekleştirildiği tesislerdir. Bu tesisler, enerjiyi doğrudan tüketim noktalarına yakın bölgelerde üretir ve dağıtır. Dağıtık üretim, geleneksel merkezi enerji üretimine alternatif bir yaklaşım olarak ortaya çıkmıştır. Dağıtık üretim tesisleri genellikle yenilenebilir enerji kaynaklarına dayanır. Bunlar arasında güneş enerjisi panelleri, rüzgar türbinleri, hidroelektrik jeneratörler, biyokütle ve mikrohidroelektrik gibi kaynaklar yer almaktadır. Bu tesisler, yerel enerji talebini karşılamak amacıyla küçük ve ölçeklenebilir bir şekilde inşa edilebilmektedir (Şimşek 2011).

Dağıtılmış enerji üretim sistemlerinde (DEÜS), doğrudan talebi karşılamaya yönelik alçak gerilim (AG) veya orta gerilim (OG) seviyesinde (0,4-36kV) elektrik enerjisi üretimi yapılmaktadır. Enerji depolama merkezi olmayan yerel ve bölgesel ihtiyaçlara yönelik kullanılan, kaynakların optimizasyonuna, çevre ve verime dayalı en uygun çalışma yöntemleri ve kapasitesini belirleyen elektrik üretim sistemleridir. Başka bir deyişle DEÜS,

küçük güçlü üretim birimlerinin şebekeye, tüketicilerin yük ihtiyaçlarını karşılamak üzere bağlanmasıdır. Bu sistemler, tüketici merkezlerine yakın elektrik dağıtım şebekesine bağlı veya tek basına çalışabilen, coğrafi olarak yayılı kaynakları içermektedir. Bununla beraber küçük güçlü santrallerin yanında, RES gibi YES yapıları, yakıt pili ve enerji depolama birimleri de dağıtılmış üretim kaynakları olarak değerlendirilebilmektedir. Dağıtılmış üretim, literatürde farklı güç değerlerinde ele alınmakla beraber genel olarak birkaç Watt'dan 100 MW'lara kadar ulaşabilen küçük güçlü santraller olarak ele alınmaktadır. Bu bağlamda dağıtılmış üretim mikro ölçek (1-5kW), küçük ölçek (5kW- 5MW), orta ölçek (5MW-50MW) ve büyük ölçekte (>50MW) olmak üzere dört grupta sınıflandırılabilmektedir (Arsoy ve Perdahçı, 2010). Dağıtılmış enerji kaynakları, kısa tesis süresi, piyasa beklentilerine cevabındaki esneklik, farklı yakıt seçeneği, gelişmiş güç kalitesi, daha az iletim kaybı, elektrik güç sistemi güvenilirliğinde artış ve gelişmiş şebeke güvenliği gibi çok sayıda avantaja sahiptir. YES kaynaklarının DEÜS olarak kullanımı yönündeki çevresel talepler daha da artmaktadır. Ayrıca, küçük jeneratörler, güç elektroniği ve enerji depolama elemanlarındaki teknolojik gelişmeler DEÜS'nin mevcut elektrik dağıtım sistemine bağlantısında yeni fırsatlar sağlayacağı düşünülmektedir (Zhang Mao ve Chang, 2008).

Mikro şebekeler, enerji üretimi ve dağıtımı için çeşitli cihazlar kullanırken, haberleşme cihazları da bu sistemlerin önemli bir parçasını oluşturur. Mikro şebekelerde kullanılan haberleşme cihazları, enerji üretim ve dağıtım sistemlerini kontrol etmek, izlemek ve optimize etmek için gereklidir. Mikro şebekelerde kullanılan haberleşme, veri kaydı ve işlenmesi, enerji depolama vb. işlevlere sahip başlıca cihazlar aşağıda yer almaktadır.

Akıllı sayaçlar: Akıllı sayaçlar, elektrik tüketimini ölçen, veri toplayan ve ileten elektronik cihazlardır. Geleneksel sayaçlar gibi tüketicilerin evlerine veya iş yerlerine takılırlar, ancak farklı olarak, tüketimin zamanına, türüne ve miktarına ilişkin ayrıntılı bilgi sağlamaktadır. Enerji tüketimini otomatik olarak ölçebilir ve bu bilgileri düzenli aralıklarla enerji dağıtım şirketlerine göndebilirler. Böylece enerji şirketleri, tüketim verilerini gerçek zamanlı olarak takip edebilir, enerji talebini tahmin edebilir ve enerji arzını optimize edebilir (Ulusal Enerji Planı Portalı, 2023). Akıllı sayaçlar, tüketicilere de birçok fayda sağlar. Tüketiciler, enerji tüketimlerini gerçek zamanlı olarak izleyebilir, hangi aletlerin daha fazla enerji tükettiğini öğrenebilir ve enerji tasarrufu yapmak için gereken adımları atabilirler. Ayrıca, akıllı sayaçlar, geleneksel sayaçlara göre daha doğru ölçümler sağlar ve dolayısıyla tüketicilerin faturalarını daha doğru bir şekilde hesaplamalarına yardımcı olmaktadır. Akıllı sayaçların bir diğer faydası, enerji şebekesindeki arızaları daha hızlı tespit edebilmeleridir. Bu sayede enerji şirketleri, arızaları daha hızlı çözebilir ve enerji kesintilerini minimize edebilmektedir. Görüldüğü üzere; akıllı sayaçların kullanımı, enerji yönetimi ve enerji verimliliği açısından büyük faydalar sağlamaktadır.

Uzak terminal birimleri: Remote Terminal Units (RTU), Türkçe adıyla Uzaktan Terminal Birimi, endüstriyel otomasyon ve kontrol sistemleri için kullanılan bir cihazdır. RTU'lar, çeşitli sensörlerden veya diğer veri kaynaklarından gelen verileri toplar, bu verileri işler ve sonuçları kontrol merkezine veya diğer RTU'lara ileten bir iletişim arayüzüne sahiptir (Baran, 2021). RTU'lar, genellikle dağıtık kontrol sistemleri veya SCADA (Gözetim Kontrol ve Veri Toplama Sistemi) sistemlerinin bir parçası olarak kullanılırlar. Endüstriyel işletmelerde genellikle RTU'lar, örneğin enerji dağıtımı, petrol ve gaz boru hatları, su arıtma tesisleri ve diğer benzer tesislerde kullanılırlar (Baran 2021). RTU'lar, saha cihazlarının verilerini toplamak, işlemek ve kontrol merkezine iletmek için kullanılan bir araçtır. Bunlar, sensörler, veri toplama cihazları, röleler, motor sürücüleri gibi cihazlarla haberleşebilir ve bunların kontrolünü sağlayabilir. RTU'lar, birçok farklı haberleşme protokolüyle uyumlu olabilirler, bu da endüstriyel tesislerde farklı cihazlar arasındaki veri alışverişini kolaylaştırır. RTU'ların temel özellikleri arasında yüksek güvenilirlik, uzun ömür, düşük güç tüketimi ve uzaktan erişim özellikleri yer almaktadır. Bu özellikleri sayesinde, RTU'lar, endüstriyel işletmelerin verimliliğini artırmak, enerji tasarrufu sağlamak ve güvenliği artırmak için kullanılabilirler.

Enerji depolama kontrol sistemleri: Enerji üretimi ve tüketimi arasındaki dengesizliği gidermek ve elektrik şebekesindeki enerji arzını düzenlemek için kullanılan cihazlar veya sistemlerdir. Bu sistemler, elektrik şebekelerindeki enerji istikrarını sağlar, enerji verimliliğini artırır ve yenilenebilir enerji kaynaklarının kullanımını artırarak karbon salınımını azaltırlar. Enerji depolama sistemleri, farklı teknolojiler kullanarak çalışabilirler.

Süper kapasitörler: Süper kapasitörler, düşük enerji depolama kapasitelerine sahip olsalar da, hızlı şarj-deşarj özellikleri nedeniyle bazı endüstriyel uygulamalarda kullanılabilirler.

Enerji depolama sistemleri, özellikle yenilenebilir enerji kaynaklarının kullanımı ile birlikte artan bir şekilde kullanılmaktadır. Yenilenebilir enerji kaynakları, rüzgar ve güneş enerjisi gibi, doğal olarak dönüşümlüdür ve enerji üretimi dalgalıdır. Enerji depolama sistemleri, bu dalgalanmaları dengelemek için kullanılabilmekte ve böylece enerji şebekelerindeki istikrarı sağlamakta aktif rol oynamaktadır.

Mikroçipler: Mikroçipler, mikro şebekelerin kontrol ve yönetimi için önemli bir araçtır. Mikro şebekeler, küçük ölçekli enerji üretimi ve tüketimi sistemleri olarak tasarlanmıştır ve RES, GES ya da batarya üniteleri gibi birçok farklı kaynaktan enerji alabilmektedir. Mikroçipler, bu kaynaklardan gelen enerjiyi toplama, depolama, yönetme ve dağıtma süreçlerinde önemli bir rol oynarlar. Enerji verimliliğini artırmak için tasarlanmış mikroçip temelli cihazlar mikro şebeke sisteminin istikrarını sağlamak için güç akışını izleyebilirler. Bu cihazlar ayrıca, mikro şebekelerin iletişim ve haberleşme işlevlerini de kontrol edebilirler. Farklı cihazlar arasında veri aktarımını gerçekleştirmek için kullanılabilirler ve mikro şebekelerin enerji yönetimi, izleme ve kontrolü için gereken verileri toplayabilirler. Mikro şebekelerin güvenliğini sağlamak için de kullanılmaktadır. Şebeke sistemlerine saldırıları tespit etmek için kullanılabilir ve saldırıların etkilerini minimize etmek için gereken önlemleri alabilirler. Sonuç olarak, mikroçipler, mikro şebekelerin yönetiminde önemli bir rol oynarlar ve enerji verimliliği, güvenlik ve istikrar için önemli bir araçtır. Bu haberleşme cihazları, mikro şebekelerin daha akıllı ve verimli bir şekilde çalışmasına yardımcı olurken, aynı zamanda enerji üretimi ve dağıtımını daha güvenilir hale getirmektedir.

İnvertörler ve güç çevirim sistemleri: İnvertörler ve güç çevirim sistemleri, enerjinin bir formdan diğerine dönüştürülmesini sağlayan cihazlar veya sistemlerdir. Özellikle yenilenebilir enerji kaynaklarından elde edilen doğru akım (DC) enerjisinin alternatif akıma (AC) dönüştürülmesinde kullanılmaktadırlar (Çetin, İplikci ve İçli, 2013). İnvertörler, genellikle RES, GES ve batarya tabanlı enerji depolama sistemleri gibi uygulamalarda üniteler arası enerjinin dönüştürülerek aktarımında aktif rol oynamaktadırlar. İnvertörlerin kullanımı, YES'lerde önemli avantajlar sağlar. Örneğin, GES'ler de invertörler, güneş panellerinden elde edilen DC enerjiyi şebekeye uyumlu AC enerjiye dönüştürerek elektrik şebekesine geri besleme yapabilir. Böylece, evler veya ticari binalar kendi enerjilerini üretebilir ve fazla ürettikleri enerjiyi şebekeye satabilirler. Ayrıca, batarya tabanlı enerji depolama sistemlerinde invertörler, batarya tarafından sağlanan DC enerjiyi AC enerjiye dönüştürerek evlerde veya ticari tesislerde kullanılabilir enerjiye dönüştürebilir. Bu sayede, bataryalarda depolanan enerjiyi, enerji talebinin arttığı durumlarda kullanmak veya şebekeye geri satmak mümkün olur. İnvertörler ve güç çevirim sistemleri, enerji verimliliğini artırmaya, enerji kaynaklarının etkin bir şekilde kullanılmasına ve yenilenebilir enerji sistemlerinin entegrasyonuna yardımcı olmaları nedeni ile elektrik şebekesi üzerindeki yükü dengeleyebilir ve enerji talebinden kaynaklı dalgalanmaların bastırılmasında aktif görev alırlar.

Sınır Kontrol / SCADA Çözümleri: Sınır Kontrol (Border Control) ve SCADA (Supervisory Control and Data Acquisition) çözümleri, çeşitli endüstriyel ve altyapı sistemlerinin izlenmesi, kontrol edilmesi ve yönetilmesi için kullanılan teknolojik sistemlerdir. Her biri farklı amaçlara hizmet etse de genellikle büyük ölçekli enerji, su, gaz, telekomünikasyon ve ulaşım gibi kritik altyapı sistemlerinde yoğun olarak tercih edilirler (Erdem, Keleş, Hamamcı ve Tan 2013). SCADA sistemleri, endüstriyel ve altyapı sistemlerinin izlenmesi, kontrol edilmesi ve veri toplamak için kullanılan bir tür otomasyon sistemidir. Enerji üretim ve dağıtım sistemleri, su ve atık su arıtma tesisleri, petrol ve gaz boru hatları, telekomünikasyon ağları ve ulaşım sistemleri gibi geniş bir alanda kullanılır. Bu sistemler, sahadaki sensörler ve cihazlar aracılığıyla gerçek zamanlı verileri toplar, kontrol merkezlerinde bu verileri izler ve operatörlere sistemleri etkin bir şekilde yönetme imkânı sunarlar. Operatörlerin sistem performansını takip etmesine, hataları tespit etmesine ve sistem verimliliğini artırmasına yardımcı olurlar (Erdem, Keleş, Hamamcı ve Tan 2013).

Mikro Şebekelerde Akıllı Yönetim Uygulamaları (Akıllı Şebekeler)

Etki alanı, bileşen sayısı ve çalışma gerilimi aralığını ne olursa olsun şebekelerin daha verimli, güvenli ve yönetilebilir olması için Akıllı Şebeke (Smartgrid) kavramı ortaya çıkmıştır. Akıllı şebeke geleneksel elektrik şebekelerine bilgi ve iletişim teknolojilerinin entegrasyonuyla oluşturulan gelişmiş bir elektrik dağıtım ağıdır. Şebekenin elektrik üretimi, iletimi, dağıtımı ve tüketimi üzerinde daha fazla kontrol ve yönetim sağlamayı amaçlamaktadır. Geleneksel şebekelere kıyasla daha esnek, verimli, güvenilir ve sürdürülebilir bir enerji dağıtım sistemini hedeflemektedir. Sensörler, akıllı ölçüm cihazları, kontrol sistemleri ve veri analitiği gibi çeşitli teknolojik unsurları ve hatta YES yapıları barındıran akıllı şebekeler enerji tüketimini ölçme, verileri

toplama, toplanan veriyi analiz etme ve enerji akışını optimize etmek için bilgi ve komutları iletim hatları üzerinden iletebilirler. Akıllı şebekeler genel olarak aşağıdaki görevleri yerine getirebilirler.

İzleme ve ölçüm: Akıllı şebeke, enerji üretimini, iletimini ve tüketimini sürekli olarak izlemekte ve kayıt altına almaktadır. Bu, gerçek zamanlı veri toplamayı sağlar ve operatörlere şebeke durumunu tam olarak anlama ve analiz etme imkanı sağlamaktadır.

İletişim ve veri yönetimi: Akıllı şebeke, iletişim ağları kullanarak şebeke bileşenleri arasında veri transferini sağlamaktadır. Bu, operatörlere veri analizi, karar verme ve sistem optimizasyonu için gerekli bilgileri sunmaktadır.

Dağıtım yönetimi: Akıllı şebeke, enerji dağıtımını optimize etmek için gerçek zamanlı verileri kullanır. Talep tepkisine dayalı yönetim, enerji talebini düzenleyerek aşırı yüklenmeyi önler ve kaynakları daha verimli bir şekilde kullanılmasına olanak sağlamaktadır.

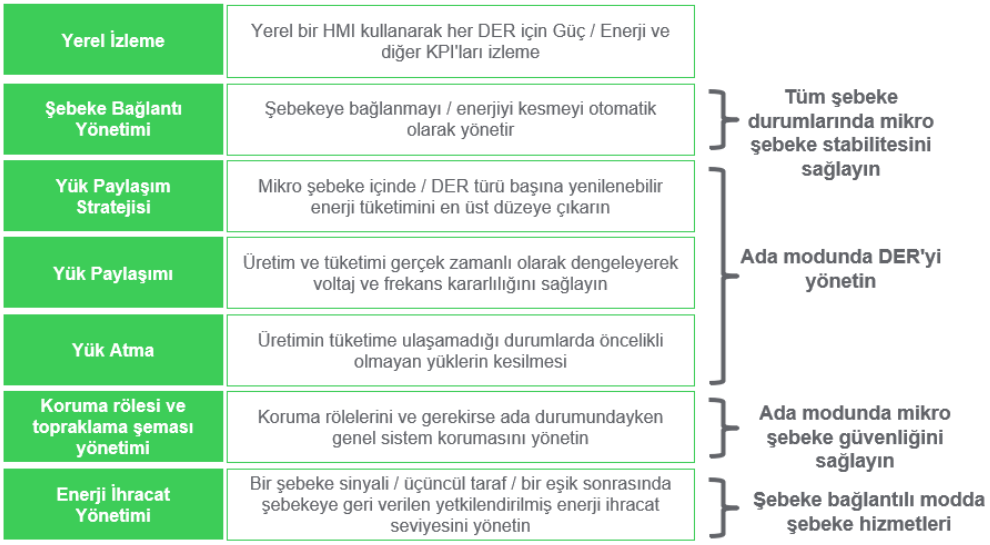
Güvenlik ve güç kalitesi: Akıllı şebeke, güvenlik önlemleri ve güç kalitesi yönetimiyle enerji ağına karşı tehditlere karşı koruma sağlamaktadır. Kesintileri hızlı bir şekilde tespit ederek otomatik olarak alternatif enerji kaynaklarına geçebilmektedir.

Yenilenebilir enerji entegrasyonu: Akıllı şebeke, YES entegrasyonunu kolaylaştırır. GES, RES ve diğer YES'lerden elde edilen enerjinin şebekeye entegre edilmesi ve yönetimi için gerekli altyapıyı sağlamaktadır.

Tüketici katılımı: Akıllı şebeke, tüketicilere enerji tüketimlerini izleme ve yönetme imkânı sunar. Akıllı ölçüm cihazları ve interaktif uygulamalar aracılığıyla, tüketiciler enerji kullanımıyla ilgili gerçek zamanlı bilgilere erişebilir ve enerji tasarrufu sağlamak için tüketimlerini yönetebilirler.

Microgrid Advisor Akıllı Mikro Şebeke Yazılımı

Yönetim açısından mikro şebekelerde makine öğrenimi gibi gelişmiş algoritmalar ile destekli yazılım ve uygulamaların kullanımı için çok önemlidir. Elektrik tedariği gibi süreçlerde akıllı karar verme yapıları kullanarak optimizasyon sağlanabilmektedir. Bu yolla mikro şebekelerin enerji talebi ve üretimi arasındaki dengenin en iyi şekilde sağlanması olanaklı olabilmektedir. Örneğin, makine öğrenimi algoritmaları, mikro şebekenin ne kadar enerji üretmesi gerektiğini tahmin edebilir ve depolama sistemlerinin ne zaman kullanılacağını belirleyebilir. Bu, mikro şebekelerin enerji verimliliğini artırabilir ve enerji maliyetlerini düşürebilir. Enerji kaynakları arasındaki bağlantıyı kontrol edebilir, hangi kaynakların en verimli şekilde kullanılacağına karar vermek için kullanılabilir ve bunun sonucunda enerji tedarik zinciri optimize edilebilirler. Şekil 1 ile Schneider Elektrik firması tarafından mikro şebekelerin yönetimine yönelik özel olarak geliştirmiş makine öğrenimi destekli bir sınır kontrol SCADA yazılımı olan Microgrid Advisor'ün ana değer yargıları görülmektedir.



Şekil 1. Microgrid Advisor Sınır kontrol SCADA yazılımının ana değer yargıları (DER: Distributed Energy Resource: Dağıtılmış Enerji Kaynakları)

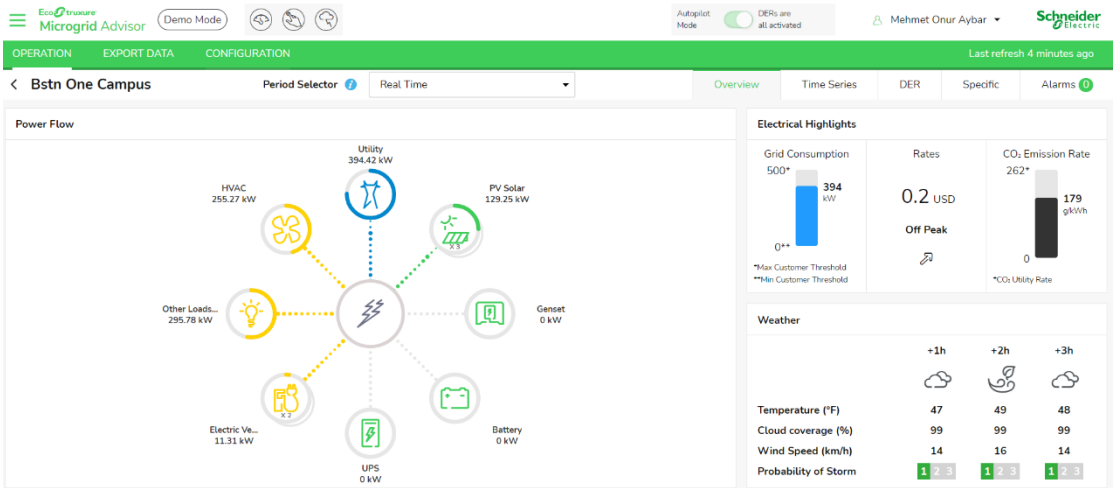
Bulut tabanlı olarak geliştirilen Microgrid Advisor yazılımı aracılığı ile DER kurulu sisteminin birbirleri arasında en optimum kullanım modelini oluşturmalarına olanak sağlanmaktadır. Söz konusu yazılım Şekil 2 ile detaylandırılan değer yargılarını kullanarak tarife yönetimi, batarya yönetimi, tahmin yapısı ve farklı mikro şebeke mimarilerinin desteklenmesi gibi yönetimsel fonksiyonları yerine getirebilmektedir.

Uzaktan İzleme ve Tahmin	Web erişimi kullanarak her DER için Güç / Enerji ve diğer KPI'ları izleme Elektrik / termal enerji
Tarife Yönetimi	Değişken elektrik tarife oranına göre DER (enerji tüket/üret/depola) kontrolü Elektrik / termal enerji
Talep Ücreti Azaltma	Tesis tüketim zirvesini azaltmak için DER'yi kontrol edin (enerji tüketin/üretin/depolayın)
Öz Tüketim	PV sisteminden enerji tüketimini en üst düzeye çıkarmak için enerji depolama ve PV sistemini kontrol edin
Talep Yanıtı*	Şebekeden gelen talep kısıtlama mekanizmalarına katılmak için DER'i kontrol edin
Frekans Düzenleme*	Frekans düzenlemesini desteklemek için yerel üretimi ve BESS'i kontrol edin (DER Kutusunda verel mantık)
Şebeke Kesinti Modu Hazırlığı	Gelecekteki şebeke dışı olayları öngörmek için DER'i kontrol edin
Enerji Satış Yönetimi	Şebekeye enerji ihraç etmekten kaçınmak için DER'i kontrol edin

Şekil 2. Mikro şebeke yazılımının ana değer yargıları (Schneider Portalı, 2023)

Mimari Yönetimi: Yazılımın etkili olduğu sahalarda birbirinden farklı şebeke modelleri kullanılabilmektedir. Bu nedenle sahaya ait özel şebeke mimarisini ve yönetim enstrümanlarını kullanıcılar kolaylıkla takip edip operasyonel ihtiyaçlarını karşılayabilmektedir. Şekil 3 ile sunulan tek saha görümü bulut haberleşme vasıtasıyla, verinin alındığı kaynaklar hakkında tek ekran üzerinden hareketliliği göstermektedir. Kullanıcı için kolay ve anlaşılır olmasının yanında, tek bir ekrandan takip edilebilme avantajı ile saha içindeki hava durumu koşulları ve elektriksel karakteristikler gibi önemli veriler tek ekran üzerinden aktarılmış olur. Tek saha görünümün içeriğinde sunulan yönetim fonksiyonları aşağıdaki gibidir.

- Tüm dağıtılmış enerji kaynakları için gerçek zamanlı kW görünümleri
- Şebeke ve yerinde üretim değerleri
- Yerel hava durumu verileri
- Sürdürülebilirlik performansı
- Üretim ve tüketim öngörüsü
- Geçmişe dönüş detaylı raporlama
- Kullanıcı senaryolarına göre alarm verme



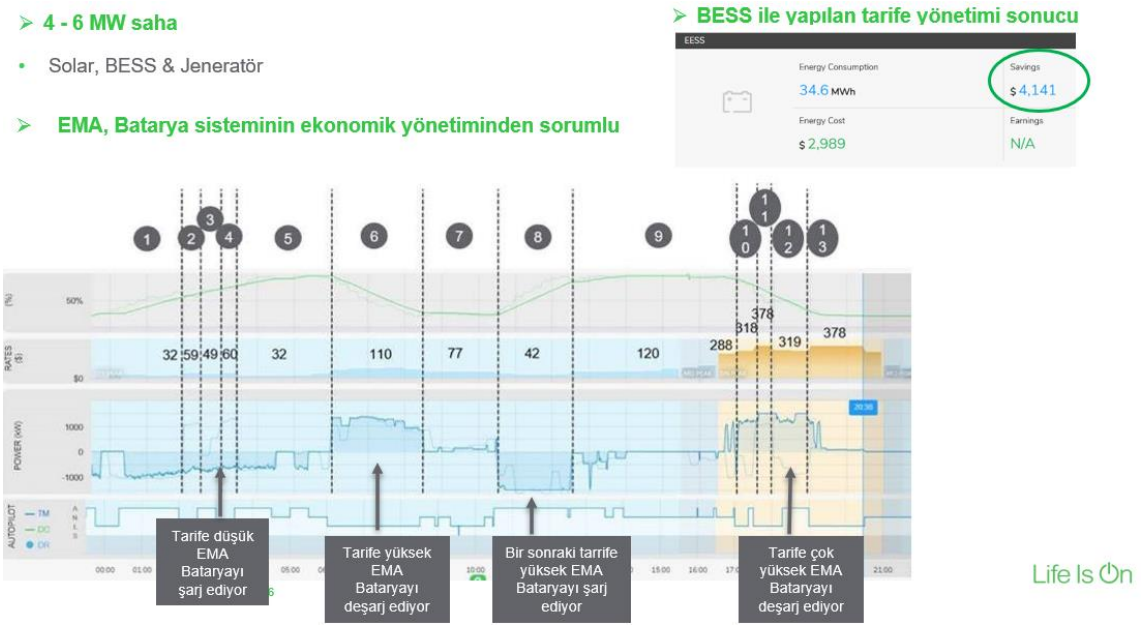
Şekil 3. Tek saha görünümü

Anlık yüksek talep (peak) tıraşlama veya talep ücreti azaltma: Yazılımın değer yargılarından birisi de anlık yüksek talebi tıraşlayarak talep ücreti azaltmaktır. Bunu yapabilmek için 24 saatlik canlı tahmin senaryolarında ne zaman yüksek talep olacağını öngörüp depolama sistemlerini SCADA sistemi ile devreye sokarak şebekeden çekilen enerjinin azalmasına ve bu sayede talep ücreti optimizasyonunun sağlanmasına olanak tanımaktadır (Şekil 4).

Şekil 4. Anlık yüksek talep (peak) tıraşlama veya talep ücreti azaltma

İlgili şekilde de görüldüğü gibi 'off-peak' zamandan 'mid-peak' zamana geçildiğinde talep miktarı ve enerjinin birim maliyetinde artış meydana gelmektedir. Yazılımın kullanılmadığı bir senaryoda anlık artan talebin tamamı güç şebekesinden karşılanacağı için normal tarifenin çok daha üstünde bir birim maliyet ile enerji tüketilecektir. Ancak yazılımın devreye girmesi ile bu ihtiyacın batarya depolama sisteminden ya da güneş enerji santralinden karşılanması ile maliyetler azaltılmıştır. Bu sayede yıllık ortalama 30% civarında enerji faturalarında tasarruf sağlanabilmektedir.

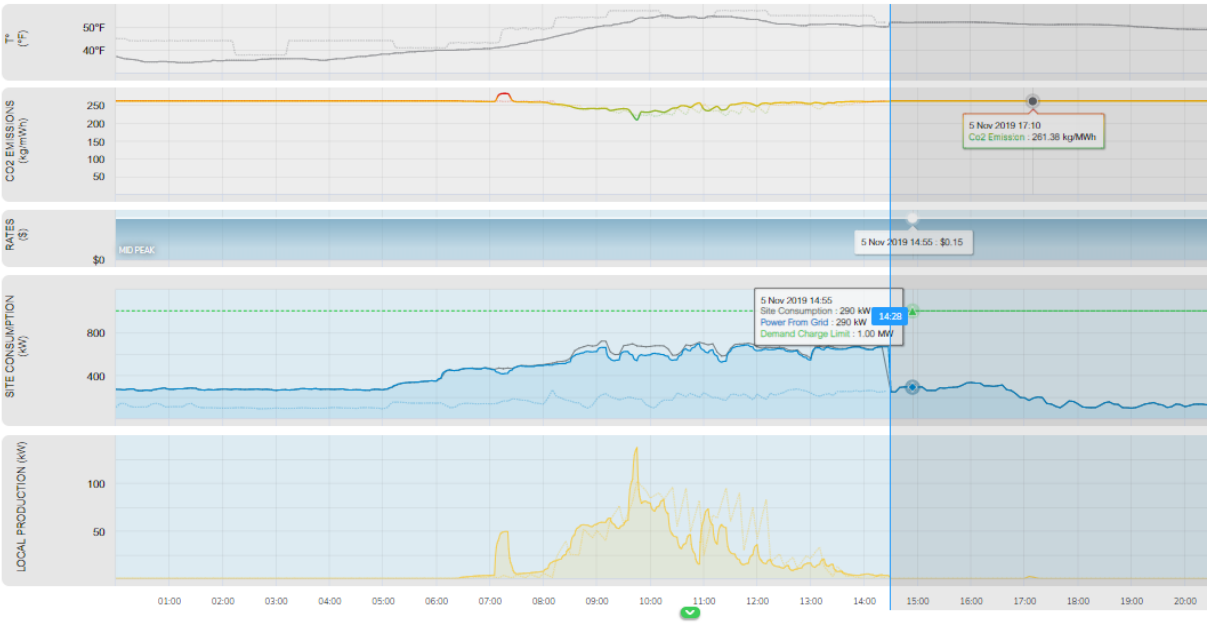
Tarife yönetimi: Microgrid Advisor yazılımın sağladığı değer yargılarından bir tanesi de akıllı elektrik tarife yönetimidir. Değişken zamanlı elektrik tarifesinin olduğu sahalarda yazılıma hangi tarifenin ne zaman devreye gireceği bilgisi girilir. Algoritmalar vasıtasıyla optimum çalışma koşullarının sağlanması için 24 saatlik süreçte hangi tarife aralığında nasıl bir çalışma modeli olması gerektiği yazılım tarafından kurgulanmaktadır (Şekil 5).



Şekil 5. Tarife yönetimi

Yukarıdaki şekilde görüldüğü gibi elektrik tarifesinin düşük olduğu zaman diliminde yazılım sahadaki batarya depolama sistemlerinin şarj edilmesi emrini verir. Bu sayede tarifenin yüksek olduğu zaman diliminde bataryalar deşarj edilerek en verimli uygulama modeli sağlanmış olur.

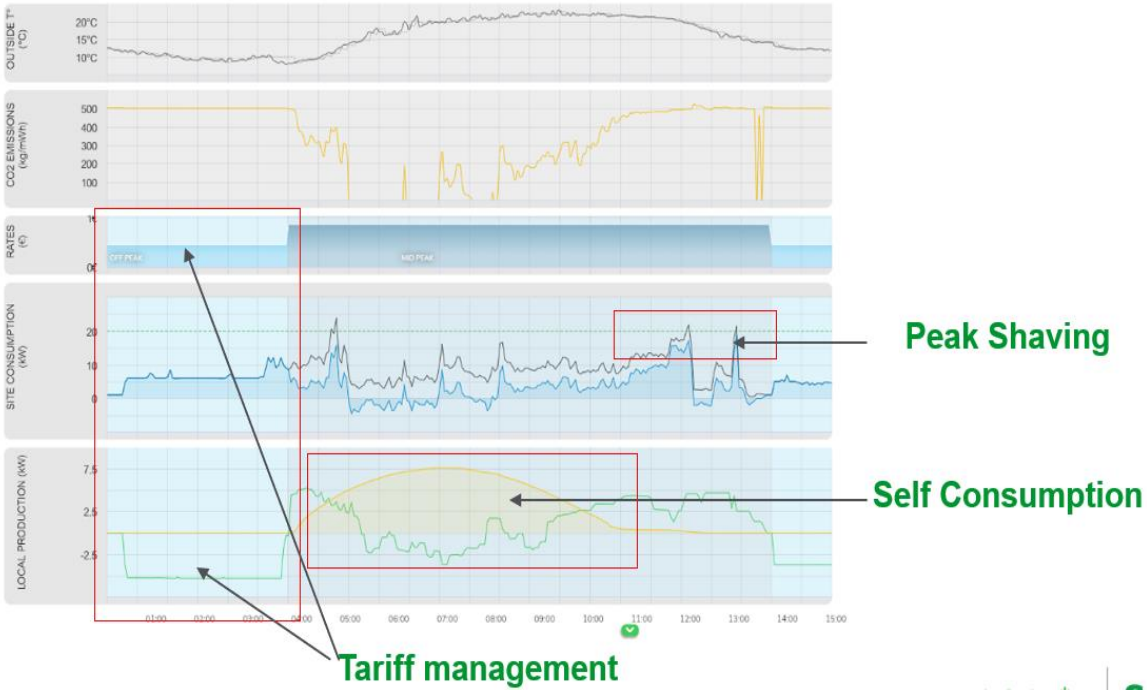
Gelişmiş tahmin: Yazılımın değer yargılarından birisi de gelişmiş tahmin özelliğidir. Bu özelliği vasıtasıyla önümüzdeki 24 saatlik süreçte; üretim, tüketim, depolama, CO2 emisyon değerleri 99% doğruluk oranı ile kullanıcıya sunulmaktadır. Bu amaçla 2 senelik verilerin sürekli olarak depolanmakta ve bu veriler ile modelleme çalışmaları yaparak olası senaryolar oluşturulmaktadır. 3 saatlik periyotlarla sürekli olarak yenilenen hava tahmin raporu da yerel üretim değerlerinin ne olacağı konusunda yüksek doğruluk ile varsayım yapabilmektedirler (Şekil 6).



Şekil 6. Gelişmiş tahmin

Yukarıdaki görselde sıcaklık, CO2 emisyon değeri, saha tüketimi ve yerel üretimin gerçek zamanlı görünümü incelenebilmektedir. Gelişmiş tahmin sayesinde saha oto-pilot yöntemi ile ya da manuel olarak yönetilebilmektedir.

Batarya depolama sistemi ve PV ile gerçek zamanlı öz tüketim optimizasyonu: Sahada güneş enerji sistemi ile beraber çalışan batarya depolama sistemi olması durumunda, yazılım gerçek zamanlı öz tüketim optimizasyonu yapmaya olanak sağlamaktadır. Bunu yapabilmek için olası üretim senaryosundaki veriden faydalanarak güneşin üretiminin arttığı zaman dilimlerinde depolama yaparak operasyonu yönetmektedir (Şekil 7). Bu sayede öz tüketim için ihtiyaç duyulan enerjinin sıfır emisyon koşullarında sağlanışı olanaklı hale gelmektedir.



Şekil 7. Batarya depolama sistemi ve PV ile gerçek zamanlı öz tüketim optimizasyonu

Yukarıdaki şekilde de görüldüğü gibi öz tüketim için ihtiyaç duyulan enerjinin güneşli bir günde hem güneşten hem de güneşin olmadı bir saat aralığında batarya dan sağlanmasıyla elektrik faturasında fiyat azaltımı yapılmaktadır. Ayrıca bu yolla CO2 emisyon değerlerinde de olabildiğince düşüş elde edilmektedir.

Elektriksel mimari: Yazılımın kullanılması için gerekli elektriksel mimari olabildiğince basit ve marka bağımsız olarak uygulanabilmektedir. Kullanım modellerini çıkarabilmek için öncelikle üç ana bağlantı modundan hangisinde olunduğuna göre model kurgulanmalıdır. Aşağıda her bir ana bağlantı modu için gereken elektriksel mimari ayrı ayrı tartışılmaktadır.

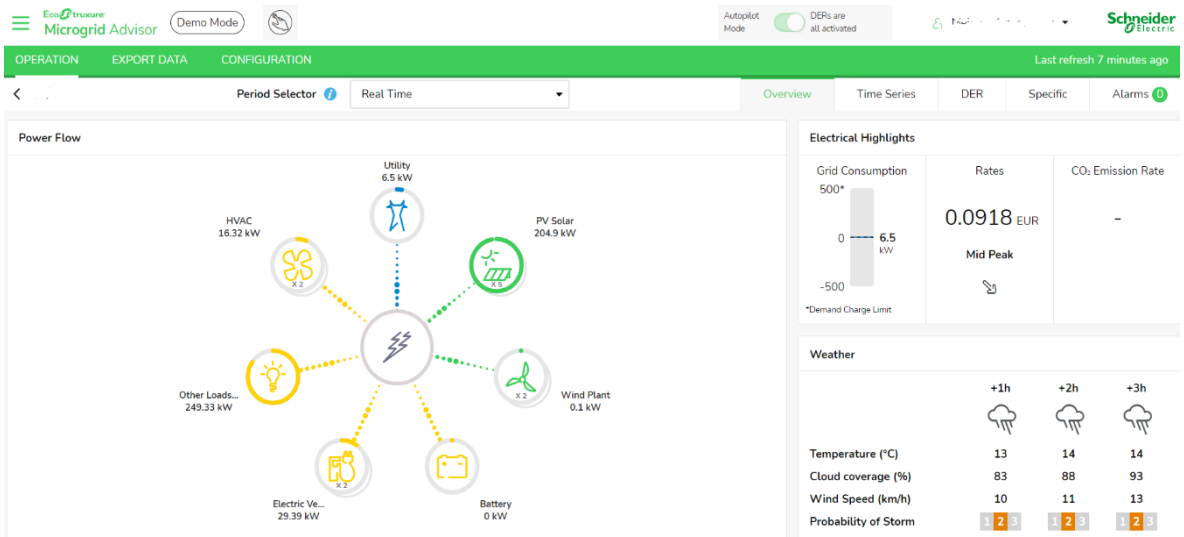
Şebekeye bağlı yapı: Ülkemizin de içinde bulunduğu, dünya genelinde en yaygın olarak kullanılan model, ana güç şebekesine bağlı yapı modelidir. Bu modelin uygulama amacı olası bir kesinti sırasında tüm enerjinin ikincil kaynaklardan sağlanması değil, elektrik maliyetlerinin optimizasyonudur. Kullanıcının birincil ihtiyacı elektrik faturasını azaltarak, CO2 emisyon verilerini düşürmektir.

Ada modeli: Bu modelin isminden de anlaşılacağı üzere olası bir elektrik kesintisi durumunda operasyonların devamlılığı birinci önceliktir. Oteller ve hizmet sahalarında yaygın olarak kullanılan ada modeli, ana güç şebekesine entegre olduğu gibi onsuz da çalışabilmektedir. Bu modeldeki uygulama amacı olası bir kesinti sırasında enerjinin ikincil kaynaklardan sağlanması ve kritik yükler için operasyonların kesintisiz olarak devam etmesidir. YES'lerin destekleyici olarak kullanıldığı bu modelde elektrik maliyetlerinin optimizasyonu da ucuz enerji ile sağlanmaktadır.

Şebeke dışı model (off-grid): Bu model genellikle kırsal kesimlerde, deniz ve okyanuslardaki adalarda ya da askeriye gibi stratejik alanlarda kullanılır. Dünya genelinde yaygın bir model olmamakla birlikte herhangi bir güç şebekesine bağlı değildir. Bu modeldeki uygulama amacı enerjinin tamamıyla ikincil kaynaklardan sağlanması ve operasyonların kesintisiz olarak devam etmesidir. Genellikle güneş enerji sistemleri, rüzgar enerjisi ya da jeneratör gibi kaynaklar bir arada kullanılarak enerji ihtiyacı sağlanmaktadır.

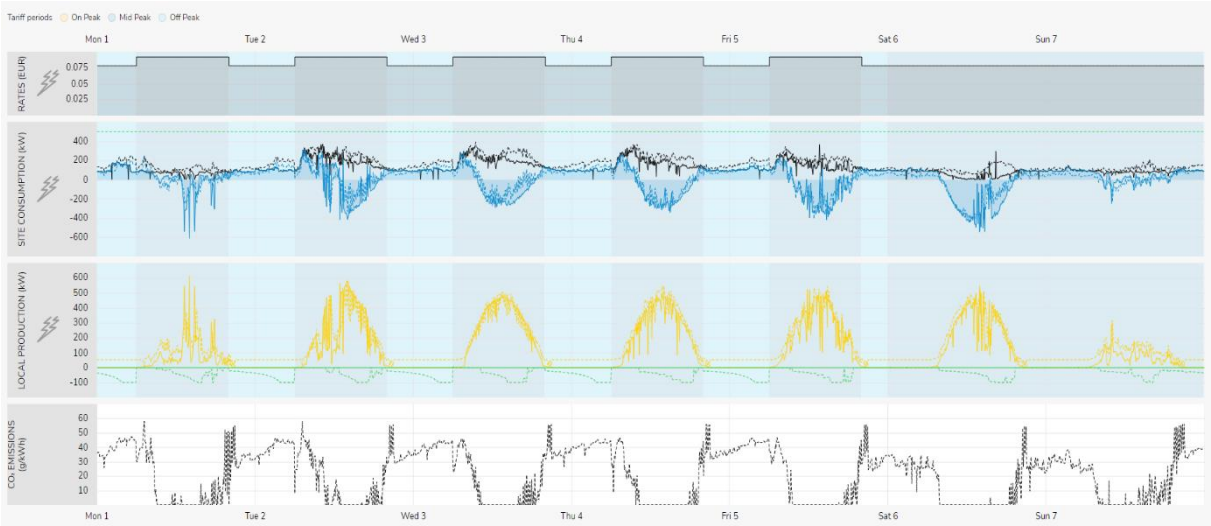
Saha Uygulaması

Çalışmanın bu bölümünde Microgrid Advisor yazılımı ile yönetimi sağlanan bir saha modelinin Demo modundaki çalışması detaylı olarak incelenmektedir. Şekil 8 ile sunulan görselde saha modeline ait tek saha görünümü yer almaktadır.



Şekil 8. Demo saha uygulaması

Yukarıdaki şekilde görünen sahada anlık olarak enerji ihtiyacı güneş panelleri ile sağlanmaktadır. Güç akış diyagramında yeşil renkli olan kaynaklar ve üreticileri, sarı renkli olanlar ise tüketicileri göstermektedir. Mavi renkli görünen kaynak ise ana güç şebekesi olup ihtiyaç fazlası enerjinin satılmasına da olanak sağlamaktadır. Görselin sağ üst köşesindeki kutucuklar vasıtasıyla detaylı zaman serilerine, tüm DER yapılarının özel grafik ve verilerine ve oluşturulmuş alarmlara ulaşılabilmektedir. Yine sağ köşede görünen elektriksel değer ve resimler sahaya ait tarife değerine, anlık CO2 emisyon verisine, hava tahmin raporlarına ve şebeke tüketim sınırlamalarına ait anlık ve incelemesi kolay bir bakış sunmaktadır. Elektrik tarifelerinin raporlanması zaman serisi (Time Series) sekmesinden yapılabilmektedir. Şekil 9'da sahadan alınan tarif raporları görülmektedir.



Şekil 9. Elektrik tarifesinin raporlanması

Sonuçlar ve Tartışma

Yapılan çalışmada da görüldüğü gibi Microgrid Advisor gibi akıllı şebeke çözümleri ile elektrik tarifesinin zaman dilimleri bazında değişimi, saha tüketim ve üretim verisi, CO2 emisyon değerleri gibi çok sayıda veriyi sahadan toplamakta ve bu verileri kullanarak kendini optimize edebilmektedir. Ayrıca sahada yer alan DER yapılarının izlenmesi, devreye alınması, devreden çıkarılması ve çalışma rejiminin tekrar düzenlenmesi olanaklı hale gelmektedir.

Sonuç olarak, makine öğrenimi destekli yazılımlar ve uygulamalar, mikro şebekelerin verimliliğini ve yönetimini optimize etmek için kullanılabilmektedir. Yapılan bu çalışma ise Microgrid Advisor yazılım ortamının, YES'e dayalı elektrik şebekeleri gibi modern enerji sistemlerinde enerji maliyetlerini düşürmek, verimliliği artırmak ve enerji kaynaklarını optimize etmek içi önemli bir araç olduğunu ortaya koymuştur.

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TRACKING THE FOOTPRINTS OF BIO-MOLECULES: EXPLORING THE SERS TRAJECTORY

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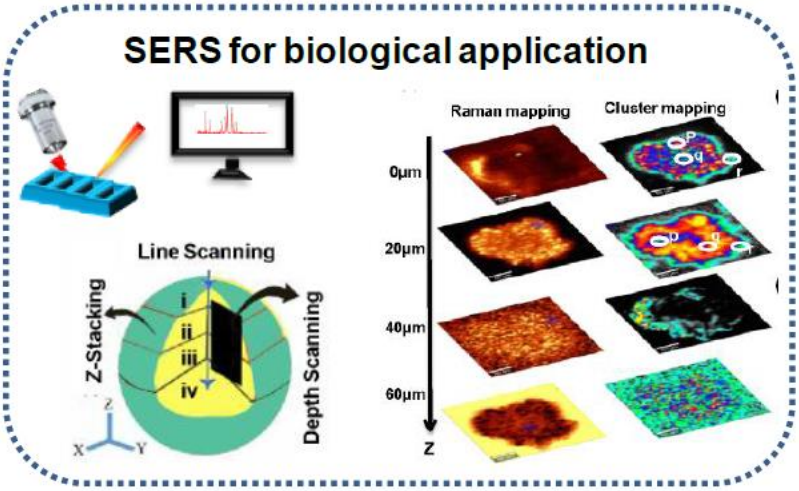
ABSTRACT

The application of Raman and surface-enhanced Raman spectroscopy (SERS) in disease detection has garnered tremendous attention in recent decades. SERS, known for its high sensitivity and non-destructive capabilities, enables the provision of unique fingerprint vibrational spectra of surface species, reaching down to the single-cell and single-molecular level.This exceptional platform holds the potential for visualizing internalization processes and monitoring therapeutic effects, particularly the challenging task of deciphering mechanistic events. In one of our study, we showcase the synthesis of a theranostic probe based on spherical and hollow gold nanoparticles, illustrating its utilization in unraveling biomolecular events. The spherical gold nanoprobe, prepared for the purpose, is employed to track internalization and microtubule disruption events associated with the non-fluorescent drug paclitaxel (PTX). For Employing SERS fingerprinting and imaging, we conducted another study to visualize the effects of a targeted theranostic platform utilizing novel hollow gold nanoparticles, thereby monitoring the molecular-level therapeutic progression of combination therapy in cells and spheroidal models. The promising findings and analytical validation presented in this work signify the necessary steps towards clinical validation, emphasizing the potential of SERS in biological applications.



Article

Raman spectroscopy is a powerful technique that can provide information about the molecular structure, composition, and interactions of various substances. However, its application in disease detection and diagnosis is limited by its low sensitivity and selectivity. To overcome this challenge, surface-enhanced Raman spectroscopy (SERS) has been developed, which exploits the enhancement of the Raman signal by the interaction of light with metal nanoparticles. SERS can offer high sensitivity, specificity, and multiplexing capabilities, as well as the ability to monitor dynamic processes at the cellular and molecular level. In the ever-

evolving landscape of biomedical research, the utilisation of advanced spectroscopic techniques has emerged as a beacon of hope for unravelling the intricacies of disease processes at the molecular level. Among these, Raman and Surface-Enhanced Raman Spectroscopy (SERS) have seized the spotlight in recent decades, captivating researchers with their remarkable sensitivity and non-destructive capabilities. This dynamic duo has paved the way for the acquisition of unique fingerprint vibrational spectra from surface species, offering unprecedented insights into the realms of single-cell and single-molecular analysis. In this work, we present studies that demonstrate the use of SERS as a theranostic tool for disease detection and treatment.

This article delves into the exceptional potential of SERS as a platform for disease detection, showcasing its ability to visualise internalisation processes and monitor therapeutic effects with unparalleled precision. A pivotal focus is placed on the synthesis and application of a theranostic probe, meticulously crafted from spherical and hollow gold nanoparticles. This innovative probe serves as a key instrument in deciphering biomolecular events, particularly those associated with the challenging task of unravelling mechanistic events.

The journey unfolds with the exploration of a spherical gold nanoprobe tailored for tracking internalization and microtubule disruption events linked to the non-fluorescent drug paclitaxel (PTX). The strategic use of SERS fingerprinting and imaging techniques in this study sheds light on the intricate interplay between therapeutic agents and cellular processes, setting the stage for a deeper understanding of drug mechanisms. The spherical gold nanoprobe utilized in this study offers several advantages in tracking internalization and microtubule disruption events. Its unique properties, such as high stability and biocompatibility, make it an ideal candidate for studying the effects of the non-fluorescent drug paclitaxel (PTX). By incorporating surface-enhanced Raman scattering (SERS) fingerprinting and imaging techniques, we are able to gain valuable insights into the complex interactions between therapeutic agents and cellular processes. This comprehensive approach paves the way for a more understanding of the underlying mechanisms of drug action and opens up new possibilities for the development of targeted therapies. Additionally, the use of SERS allows for real-time monitoring of drug uptake and distribution within cells, providing crucial information for optimizing drug dosage and delivery strategies. Moreover, the ability to track microtubule disruption events using SERS enables researchers to investigate the effectiveness of novel anti-cancer drugs and study their mechanisms of action in depth. Overall, the combination of SERS and biocompatible nanomaterials like PTX holds great promise in advancing our understanding of drug-cell interactions and revolutionizing the field of drug development. For example, researchers can use SERS to study the uptake and distribution of a chemotherapy drug within cancer cells. They can attach a SERS-active molecule to the drug and track its movement in real-time using spectroscopic techniques. This allows them to determine how quickly and efficiently the drug is being taken up by cells, as well as identify any barriers or challenges that may hinder its effectiveness. Additionally, they can use SERS to assess the impact of different drug dosage and delivery strategies on cellular uptake, providing valuable insights for optimizing drug formulations and treatment regimens. For instance, by comparing the SERS signals from cells treated with different doses or delivery methods, researchers can determine which approach maximizes drug uptake and minimizes potential side effects. This information can help guide the development of more effective and targeted drug therapies, ultimately improving patient outcomes and revolutionizing the field of cancer treatment. Furthermore, SERS can also be utilized to study the intracellular distribution of drugs within cancer cells. By tagging drugs with SERS-active molecules, researchers can track the movement of these compounds in real-time, allowing for a more comprehensive understanding of drug-cell interactions. This knowledge can aid in the development of innovative drug delivery systems that specifically target cancer cells while minimizing harm to healthy tissues. Ultimately, SERS-based techniques have the potential to revolutionize cancer treatment by providing personalized and optimized therapeutic approaches.

In a parallel endeavour, we venture into the realm of hollow gold nanoparticles, deploying them as a targeted theranostic platform. These hollow gold nanoparticles are designed to not only deliver therapeutic agents to specific cellular targets but also provide real-time imaging capabilities. By incorporating imaging agents such as fluorescent dyes or contrast agents, we are able to track the nanoparticles' journey within the body and monitor their interaction with the targeted cells. This innovative approach allows us to gain valuable insights into the efficacy and safety of the therapeutic intervention, paving the way for more precise and personalized treatments. Additionally, the hollow nature of these nanoparticles offers the potential for further functionalization, such as loading with multiple drugs or incorporating stimuli-responsive elements for controlled release. This multifunctional capability of the nanoparticles opens up new possibilities for combination therapy and tailored treatments, where different drugs can be released at specific times or in

response to certain triggers within the body. For example, researchers have successfully used hollow nanoparticles loaded with chemotherapy drugs to target and kill cancer cells. By incorporating stimuli-responsive elements, the nanoparticles can release the drugs only when they encounter specific conditions within the tumor microenvironment, minimizing side effects and improving treatment efficacy. This personalized approach allows for a more targeted and efficient cancer treatment, potentially revolutionizing the field of oncology.

Furthermore, scientists are exploring the use of stimuli-responsive nanoparticles in other areas of medicine as well. For instance, these nanoparticles could be designed to release antibiotics only when they come into contact with bacterial infections, reducing the risk of antibiotic resistance and enhancing the effectiveness of the treatment. Additionally, stimuli-responsive nanoparticles can be utilized in drug delivery systems to target specific cells or tissues, resulting in reduced toxicity and improved therapeutic outcomes. In the future, this technology could also be applied to the field of regenerative medicine, where nanoparticles could be used to promote tissue regeneration in a controlled and precise manner. Overall, the potential applications of stimuli-responsive nanoparticles are vast and offer promising advancements in various medical fields. Additionally, the potential applications of stimuli-responsive nanoparticles extend beyond drug delivery. They can be engineered to respond to changes in pH levels, temperature, or even light, opening up possibilities for targeted therapy in a wide range of diseases and conditions. The ability to precisely control the release of therapeutic agents holds immense promise for the future of healthcare, offering Moreover, the biocompatible nature of these nanoparticles reduces the chances of adverse reactions or side effects, making them an attractive option for clinical applications. Overall, the development and utilization of these versatile nanoparticles hold great promise in revolutionizing the field of medicine and improving patient outcomes. Through meticulous SERS fingerprinting and imaging analyses, our research unveils the molecular-level therapeutic progression of combination therapy in cells and spheroidal models. The promising findings and analytical validation presented in this work serve as a testament to the transformative potential of SERS in biological applications. As we navigate through the intricacies of the studies, the implications become clear—these ground breaking findings signify vital steps towards clinical validation, positioning SERS as a promising frontier in the field of disease diagnosis and treatment.

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YENİLEBİLİR ENERJİ TERCİHİ VE KAMU YARARI: GELECEK NESİLLERİN YARARI

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ÖZET

Küresel ısınma, fosil yakıtların sınırlı kaynaklar olması ve çevreye verdiği zararlar son yıllarda enerji kaynaklarında dönüşüm konusunu gündeme getirmiştir. Bu değişim özellikle tüm dünyanın sorunu olan iklim ve enerji krizinin çözümünü amaçlamaktadır. Dünyanın geleceği için en büyük sorunlardan olan iklim krizine enerji arz yöntemlerinin sebebiyet verdiği ifade edilmektedir. Enerji arzı için geleneksel yöntem olarak değerlendirilen fosil yakıt kaynaklı tesisler yenilebilir enerji kaynaklı enerji tesislere göre kurulum maliyetleri açısından daha uygun seçeneklerdir. Fakat gelecekteki faydaları düşünülerek yenilenebilir enerji teşvik edilmiş, kurulumlarına rağbet gösterilmiştir. Ülkemizde özellikle 2005 yılında yürürlüğe giren 5346 sayılı Yenilenebilir Enerji Kaynaklarının Elektrik Enerjisi Üretimi Amaçlı Kullanımına İlişkin Kanun ile enerji piyasası için değişim politikaları uygulanmaya başlamıştır. Yasama faaliyeti ile başlayan bu eğilim kamu tarafından destekler ile devam etmiştir. Bu eğilimi idare hukuku açısından değerlendirdiğimizde talep garantisi, vergi, kredi gibi maddi destekler verilmesi kamu yararı açısından irdelenecektir. Sağlanan destekler çeşitli piyasalar oluşması ve sanayi ile yakından ilişki desteklerin yanında enerji verimliliği gibi yeni kavramların doğmasına bu alanlar için yeni normatif düzenlemelerin oluşmasına neden olmuştur. Fakat dünya üzerinde iklim krizi merkezli kamuoyu oluşması ve bu kapsamda oluşan yeşil ekonomi eleştirilmiştir. Yine bu tedbirlerin ancak tüm dünya ile ortak hareket edilmesiyle fayda sağlayacağı ifade edilmiştir. Bu kapsamda ilgili çatışmalar literatür, mevzuat araştırması yapılarak kamu yararı özelinde değerlendirilecektir.

Anahtar Kelimeler: Ekonomik kamu yararı, hukuk ve ekonomi, yenilebilir enerji, kamu yararı

RENEWABLE ENERGY CHOICE AND THE PUBLIC INTEREST: BENEFIT OF FUTURE GENERATIONS

ABSTRACT

Global warming, the fact that fossil fuels are limited resources and the damage they cause to the environment have brought the issue of transformation in energy resources to the agenda in recent years. This transformation aims to solve the climate and energy crisis, which is the problem of the whole world. It is stated that the climate crisis, which is one of the biggest problems for the future of the world, is caused by energy supply methods. Fossil fuel-based facilities, which are considered as the conventional method for energy supply, are more suitable options in terms of installation costs than renewable energy-based energy facilities. However, considering the future benefits, renewable energy has been encouraged and their installations have been in demand. In our country, especially with the Law No. 5346 on the Utilisation of Renewable Energy Resources for the Purpose of Electricity Generation, which entered into force in 2005, change policies have started to be implemented for the energy market. This trend, which started with legislative activity, continued with public support. When we evaluate this trend in terms of administrative law, financial support such as demand guarantee, tax and loan will be analysed in terms of public interest. The supports provided have led to the formation of various markets and the emergence of new concepts such as energy efficiency in addition to the supports closely related to the industry and the formation of new normative regulations for these areas. However, the formation of public opinion centred on the climate crisis in the world and the green economy formed within this scope have been criticised. Again, it has been stated that these measures will only be

beneficial by acting jointly with the whole world. In this context, the relevant conflicts will be evaluated in terms of public interest by conducting literature and legislation research.

Keywords: Economic Public Interest; Law and Economics; Renewable Energy; Public Incentives

GİRİŞ

Sanayileşme, nüfus artışı, kentleşme gibi unsurların tetiklemesi ile çevre sorunları günümüzün başat sorunları arasında kabul edilmektedir. Bu sorunlar sadece ülkeler bazında değil küresel ölçekte sorunlar olup çözüm arayışları da küresel ölçekte olmalıdır. Çevreyi en çok kirleten husus enerji arzında kullanılan yöntemlerdir. Bu çerçevede çözüm arayışı enerji üretim kaynaklarının ve araçlarının değişimi geliştirilmesi etrafında kümelenmiştir. Çünkü enerji fizik kurallarına göre enerji yaratılamaz ve yok edilemez ancak dönüştürülebilir.[1] Bu bağlamda enerjinin kendisi değil arz kaynağı ve yöntemi geliştirilmeli çevreye duyarlı ve sürdürülebilir kaynaklara yönelim gerçekleşmelidir. Günümüzde ise bu sorunun çözümü ise enerjinin yenilenebilir kaynaklardan elde edilmesi olarak görülmüştür. Yenilenebilir enerji kaynaklarına yönelimi sadece çevresel etki ile açıklamak eksik olacaktır. Fosil kaynakların sınırlı oluşu ve petrol krizleri de yine enerji kaynaklarının değiştirilmesi ve geliştirilmesi için sebep olmuştur. Yenilebilir enerji kaynakları sürdürülebilir oluşu ve enerji arzının kontrolünün ülkelerin elinde olması nedeniyle bu sorunlara çözüm olarak görülmektedir. Çünkü fosil yakıtlar ülkelere düzensiz dağılmış siyasi istikrasızlıklar da doğrudan bu kaynakların dağılı/ transferi gibi süreçleri etkilemiş ve enerji krizleri patlak vermiştir. Bu durumun en yakın örneği ise Rusya- Ukrayna savaşı bağlamında doğalgaz arzında gerçekleşen dalgalanmanın Avrupa'da enerji krizine neden olmasıdır. Yenilebilir enerji arzının kontrolü kurulu olduğu ülkenin elinde olması sebebiyle enerji güvenliğini de sağlamaktadır. Kısacası yenilenebilir kaynaklı enerji çevresel ve enerji güvenliği etkisi ile sorunlara çözüm olarak görülmüştür.

Yenilenebilir enerji kaynaklarının bahsi geçen özelliklerinden dolayı ülkemiz tarafından da üretim araçları ve yöntemleri özendirilmiş ve teşvik edilmiştir. Sağlanan teşvik yöntemleri ise beraberinde paradoks doğurmuştur, şöyle ki öncelikle yenilebilir enerji kaynakları çevreye tamamen zararsız değillerdir ayrıca günümüzde sağlanan bütçenin gelecekte fayda sağlaması muhtemel bir olgu için harcanması ve çözüm üreteceğinin belirsizliği teşviklerin eleştirilmesine neden olabilecektir. Elektrik enerjisinin sunumunun kamu hizmeti olduğu kabul edildiğinde, idarenin temel amacı olan kamu yararının sağlanması *daha pahalı olan* yenilebilir enerji kaynakları vasıtasıyla elektrik üretimi bu özelde tartışılacaktır. Çünkü gelecek nesiller düşünülerek bugün tercihler yapılması kamu yararı ile örtüşmekte midir?

Bu sorunu çalışmamamızda literatür araştırması ile teorik temelde çözüme kavuşturmaya çalışacağız. Yapılan araştırmalar incelendiğinde yenilebilir enerji kaynakları çok sorgulanmadan pozitif hukuk açısından yaşanan sorunlar üzerinde çalışmalar yapılmıştır. Çalışmalar enerji arzının hukuktaki yerine odaklanmış yenilebilir enerjiye karşı olumlu önyargı bu hususun tartışılmasına engel olmuştur. Bu kapsamda amacımız yenilebilir enerji kaynakları için sağlana ayrıcalıkların kamu yararı ilkesi için temellendirilmesinin mümkün olup olmadığının irdelenmesidir. Literatür incelemesinde ulaşılan bilgiler ile yenilenebilir enerji kaynakları için izlenen ayrıcalıklı tutuma dair bilgilere erişmemiz görece kolay olmuş ve bu bilgiler çalışmamızda tartışma konusu yapılmamıştır. Çalışma kamu yararı özelinde yenilebilir enerji kaynaklarının irdelenmesine odaklanmıştır. Bu bağlamda çalışmada kullanılan veriler Enerji Enstitüsü tarafından hazırlanan istatiksel enerji raporundan (Energy Instute, 2023), Uluslararası Enerji Ajansının (IEA) tarafından hazırlanan raporlardan (IEA, 2022, 2023a, 2023b, 2023c), Uluslararası Yenilenebilir Enerji Ajansı (IRENA) tarafından hazırlanan yenilenebilir enerji maliyet raporundan (IRENA 2023), BP tarafından her yıl düzenli hazırlanan istatistiksel enerji raporundan (BP, 2022) ve Dünya Bankası data havuzundan (Dünya Bankası) yararlanılmıştır.

Çalışma kapsamında çokça bahsi geçen iklim krizi ve küresel ısınma kavramları ise atmosferde biriken sera gazlarının dünya ortalama sıcaklığını artırması küresel ısınma kavramına işaret ederken ve bu ısınmanın neticesinde dünyada gerçekleşen iklim değişiklikleri ve sonuçlarında meydana gelen olumsuz etkileri toplayan üst kavram küresel iklim krizini ifade etmektedir.[2] Yine çalışmada bahsi geçen birincil enerji kaynakları

[1] Enerjinin dönüşümü/ korunumu yasası için bkz: Feynman (1970).
[2] Ayrıntılı bilgi için bkz: https://iklim.gov.tr/

enerjinin herhangi bir dönüşüm geçirmemiş halini (kömür, petrol vb.) ifade ederken bu enerjinin dönüştürülmesi ile elde edilen kaynaklar ikincil enerji kaynaklarını (elektrik, benzin vb.) ifade eder.[3]

ARAŞTIRMA VE BULGULAR

1. Kavramsal Çerçeve

1.1. Yenilebilir Enerji ve Sağlanan Avantajlar

Enerji için yapılan "*iş yapabilme yeteneği*" genel tanımından yola çıktığımızda aslında bir iş yapabilme yeteneğinin ölçülmesidir.[4] Çünkü enerji aslında tek bir form halinde bulunmamaktadır ve çeşitli şekillerde depolanıp ölçülebilir haldedir.[5] Günümüzde teknolojini hayatımızdaki yerinden kaynaklı olarak modern toplumsal yaşamda karşımıza çıkan en büyük enerji çeşidi elektrik enerjisidir. Üretim gücü ile enerji arz ve tüketiminin doğrudan ilişkisi nedeniyle enerji gelişmişlik göstergesi kabul edilmekteydi.[6] Günümüzde ise enerji üretiminin tek başına gelişmişlik için bir parametre olarak kabul edilemeyeceği enerjinin verimliliğinin finansal gelişmişlik ile neden sonuç ilişkisinde olduğu ifade edilmiştir. Şöyle ki küresel iklim krizi, sürdürülebilirlik gibi sebeplerle verimli dönüştürülebilir enerji kaynaklarının kullanımı ve gelişmişlik arasında bağlantı olduğu görülmüştür.[7] İnsanlığın modern topluma geçişinde enerjinin dönüşümünü öğrenmesi temel etken olarak kabul edilmektedir.[8] Enerji, çevre ve kalkınma arasındaki bağlam bu kadar basit değildir[9] fakat günümüzde gelişmişliğin göstergesi sadece üretmek değil çevreye saygılı ve sürdürülebilir enerji üretimini tercih etmekten geçmektedir. Bu durum aslında ülkelerin insan haklarına; gelecek kuşaklara saygısıyla dolaylı yoldan hukukun üstünlüğüne işaret etmektedir. Bu bağlamda enerji arz yöntemi ülkelerin gelişmişlik düzeyi hakkında bilgi vermekte; yine ülkelerin dış politikalarının belirlenmesinde temel etkenlerdendir.[10] Küresel ilkim krizi ülkelerin enerji arz politikalarını belirleyen temel ölçüt haline gelmiştir.[11] Çünkü çevre sorunlarının temelinde enerji arz ve talebinin sürekli artması yatmaktadır.[12] Enerji talebi her yıl artmaktadır, küresel enerji talebi yılda ortalama %1.5 oranında artmakta enerji kaynaklarının çoğunu fosil yakıtlar oluşturmaktadır.[13] Küresel çevre sorunlarının en temelinde fosil yakıtlar yatmakta çözüm önerisi ise yenilebilir enerji kaynakları olduğu kabul edilmektedir.[14] Enerjinin elde edilmesinde *ışın enerjisi, jeotermal enerji, gelgit enerjisi ve nükleer enerji* olduğu kabul edilmektedir.[15] Enerjinin elde edilmesinde kullanılan kaynakların yerine tekrar koyulup koyulamamasına göre yenilebilir yahut yenilemeyen enerji kaynakları olarak sınıflandırıldığı görülmektedir.[16]

Yenilebilir enerji, çeşitli açılardan tanımlanmış genel özellikleri göz önüne alındığında ise "*çevrede var olan yani kaynağı doğada hazır bulunan ve insan kullanımı ile tükenmeyen/yenilenen/sürdürülebilir bir enerji kaynağı*" olarak tanımlanabilecektir.[17] Yenilenebilir enerji kaynaklarının ortak özellikleri kullanılarak tükenmemeleri; ithal olmamaları, karbon emisyonuna olumsuz katkı sağlamamaları olarak ifade edilebilir.[18] Uluslararası Enerji Ajansına (IEA) göre bu kaynakları güneş, rüzgar, hidroelektrik, biyokütle ve jeotermal enerji kaynakları olarak sınıflandırmak mümkündür.[19] Yenilenemeyen enerji kaynakları ise fosil yakıtlar olarak ifade edilmektedir. Bu bağlamda doğada hazır bulunan karbon bazlı klasik enerji kaynakları için kullanılan kavramdır. Bu kaynaklar oluşumları çok uzun zaman aldığı ve yerine kısa sürede (veya sürdürülebilir sürede)

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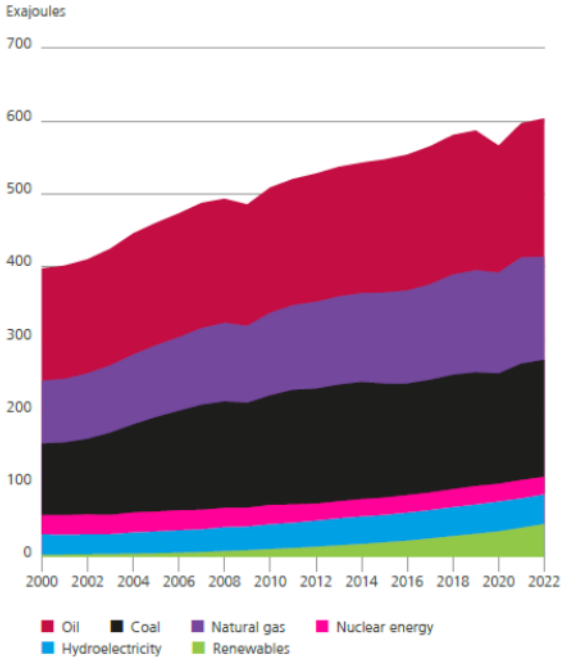
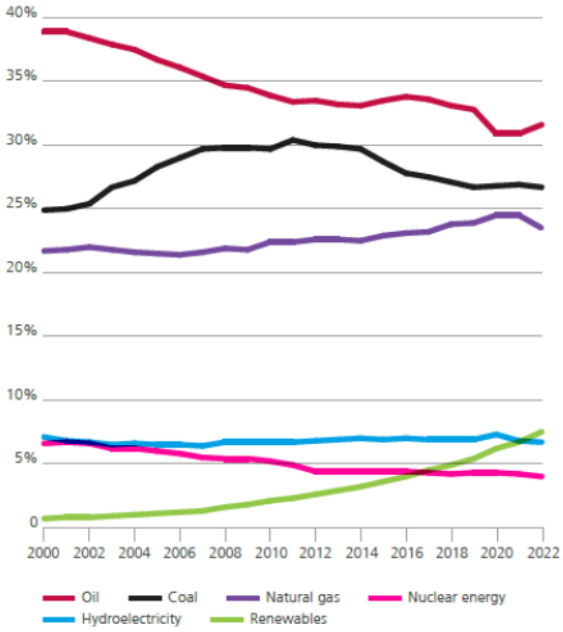
[3] Ayrıntılı bilgi için bkz: Koç/ Kaya, 2015, s. 37.
[4] https://www.britannica.com/science/energy
Sözlük anlamı ise "*Maddede var olan ve ısı, ışık biçiminde ortaya çıkan güç; erke" olarak ifade edilmektedir*." Bkz: https://sozluk.gov.tr
[5] https://www.eia.gov/energyexplained/what-is-energy/
[6] Stern/ Burke/ Bruns, 2019, s. 4vd.
[7] Yıldırım/ Akdağ, 2022, s. 667 vd.
[8] Aydın, 2015, s. 25.
[9] Çoban/ Şahbaz Kılınç, 2016, s. 591.
[10] İsmiç, 2015, s. 261.
[11] Akçay/ Bilgin, 2017, s. 869.
[12] Çoban/ Şahbaz Kılınç, 2016, s. 591
[13] Çelikkaya, 2018, s. 375.
[14] Belhamadia/ Muhammad/ Mahmoud, 2014, s. 1042.
[15] Goldemberg, 2006, s. 3.
[16] Karaaslan/ Gezen, 2017, s. 4.
[17] Çetinkaya, 2017, s. 54.
[18] Winkler, 2005, s.28. Hogg,/ O' Regan, 2010, s. 41.
[19] IEA, https://www.iea.org/energy-system/renewables

konulamadığı için yenilenemeyen enerji kaynakları olarak ifade edilir. Yenilemeyen veya yenilemez enerji kaynağı oluşma hızı tüketilme hızından düşük enerji kaynağı olarak ifade edilebilecektir.[20] Yenilenemeyen enerji kaynaklarınınım ortak özellikleri sınırlı kaynaklar olmaları, dünya genelinde düzensiz biçimde dağılmış olmaları, enerjiye dönüşmelerinde insan sağlığına/ çevreye zarar vermeleri olarak ifade edilebilir.[21] Yapılan kısa açıklama ışığında kaynakları kıyasladığımızda yenilenebilir enerji kaynakları, yenilenemeyen enerji kaynaklarına göre kendini doğal ve hızlı yenilediği, çevreye zarar vermediği sonucuna ulaşabiliriz. Görüleceği üzere yenilenebilen enerji kaynakları yenilenemeyen kaynaklara göre pek çok açıdan üstündür. Bahsi geçen avantajlara rağmen Tablo 1'de göreceği üzere dünya genelinde yenilenemeyen enerji kaynakları enerji arzında öndedir.



Tablo 1: Enerji kaynaklarının enerji üretimindeki payları (Energy Instute, 2023, s.10.)

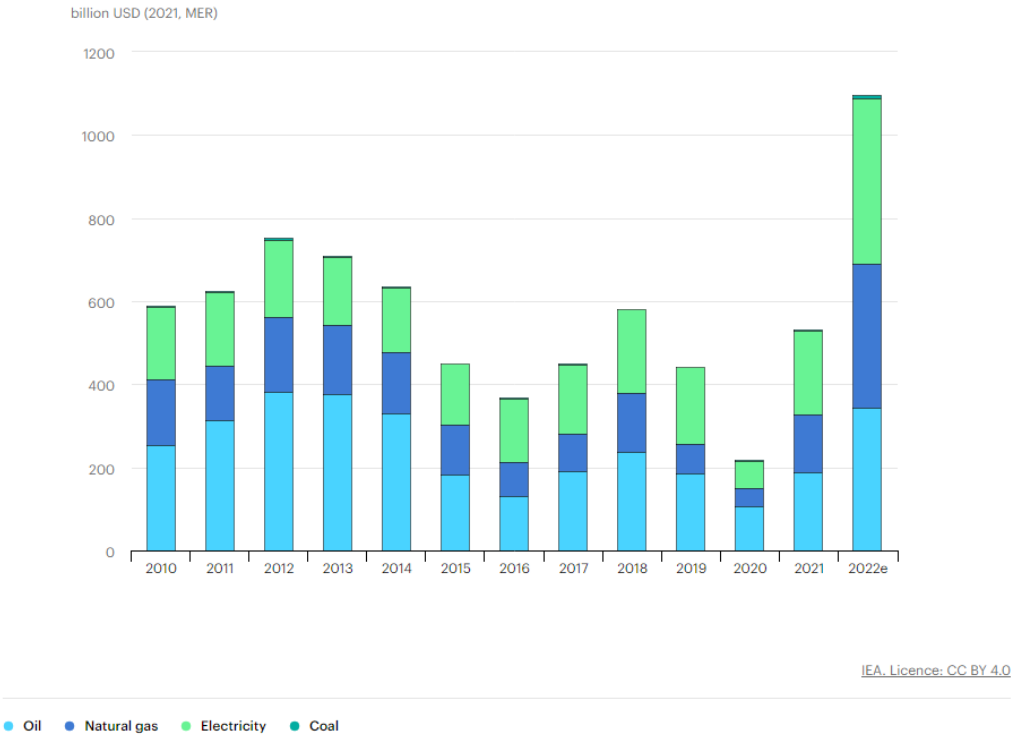


Tablo 2: Enerji kaynaklarının yıllara göre değişimi (Energy Instute, 2023, s.10.)

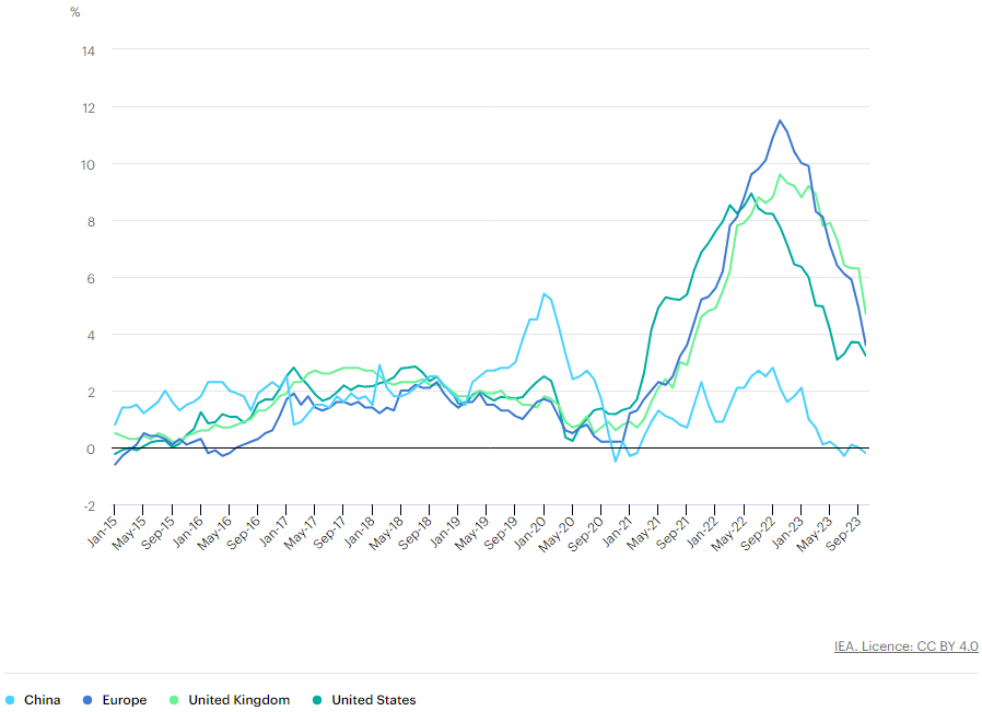
Bu durumun sebepleri olarak yenilenemeyen (fosil) yakıtlara sübvansiyonların devam etmesi[22] (Uluslararası Enerji Ajansının raporuna göre 2022 yılında rekor seviyeye ulaşmıştır (Bkz: Tablo 3)) ve kirliliğe neden olmasına rağmen fosil yakıtların maliyet hesabında bu durumun katılmaması ile yenilebilir enerji santrallerinin kurulum maliyetlerinin yüksek olması sayılabilir.[23] Fakat bu durumun değişeceğini ön görmekteyiz enerji kaynakları Tablo 2'de görüleceği üzere toplam enerji üretimindeki payını arttırmaktadır. Yine bu görüşümüzü Tablo 4'te yer alan bilgilere göre genel enflasyon oranlarındaki hareketliliğinin yenilebilir enerji kaynaklarının maaliyetlerine yansımadığını sonucuyla desteklmekteyiz. Tablo 5 incelendiğinde yenilenebilir enerji kaynaklarına dayalı enerji üretim emtialarının maaliyetinde azalma olduğu veya genel enflasyon oranını takip etmediği görülecektir. Bu durum yenilenebilir enerji kaynaklarına yönelimin olduğunu ilgili emtiaların yaygınlaştığını işaret etmektedir. Tüm bunlara ek olarak ürünlerin üretim teknolojilerinin gelişimi de bu değişime olumlu etki sağlamaktadır. Uluslararası Yenilenebilir Enerji Ajansı (IRENA) göre yenilenebilir

[20] Yapıcı/ Koldemir, (2015), s. 3.
[21] Bilginoğlu, 1991, s. 123
[22] İklim şeffaflığı 2022 raporuna göre G20 ülkelerinin toplam fosil yakıtlara sağladığı sübvansiyonlar 2020 yılında 147 milyar dolar seviyesindeyken 2022 yılında yaklaşık yüzde 29 artışla 190 milyar dolara yükselmiştir. Climate Transparency. 2022, s. 50.
[23] Çetinkaya, 2017, s. 55.

enerji piyasasında oluşan rekabet koşulları maliyet enflasyonuna rağmen 2000 yılından beri eklenen kapasiteden dolayı 2022 yılı enerji maaliyetlerini 520 milyar dolar azaltmıştır.[24]

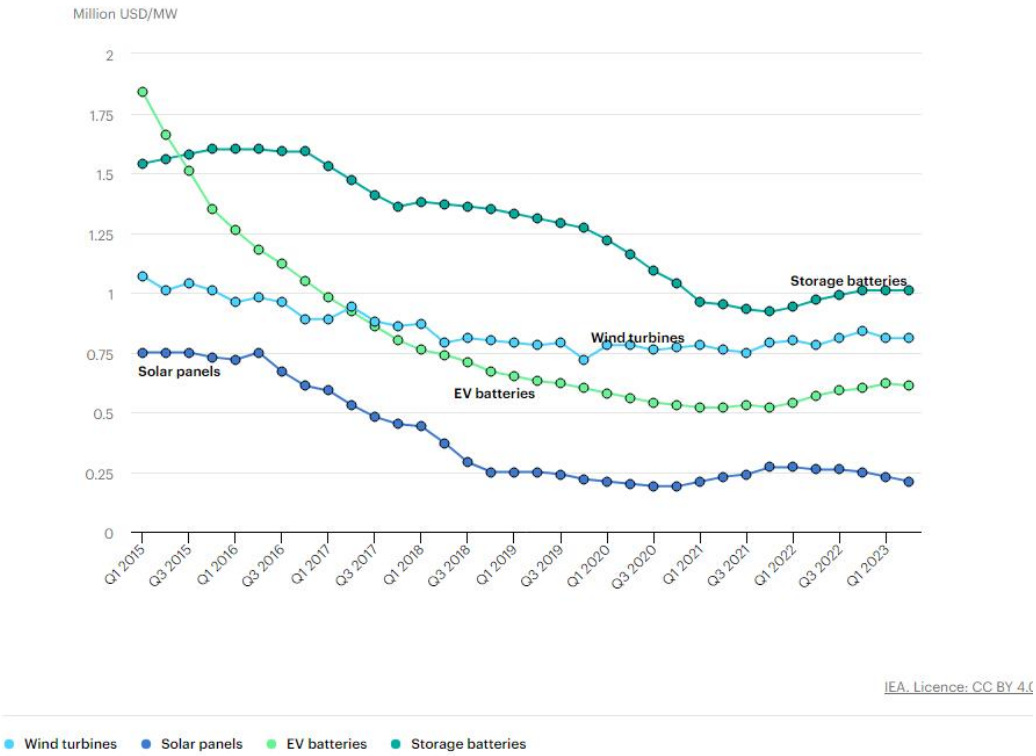


Tablo 3: Fosil yakıtlara sağlanan sübvansiyonlar. IEA, 2023a



Tablo 4: Seçili bölgelerde enflasyon oranları. IEA, 2023b

[24] IRENA, 2023, s 25 vd.



Tablo 5: Yenilenebilir enerji teknoloji fiyat indeksi. IEA, 2023c

Yakarıdaki verilen bilgiler ışığında her ne kadar istenilen seviyede olmasa da yenilenebilir enerji kaynaklı enerji arzı enflasyon ve toplam enerji arzındaki payı açısından olumlu anlamda değişmektedir. Yenilenebilir enerji kaynaklı elektrik arzının yaygınlaşmasına katkı sağlayan hususlara ülkelerin bu kaynaklara sağladıkları avantajları da ekleyebiliriz. Devletler bu anlamda 16. yüzyıldan beri yönetim politikalarına destek için sübvansiyonlar kullanmaktadırlar.[25] Bu özendirme faaliyetleri doğrudan devlet tarafından yönetilmektedir.[26] İdareler bu özendirme faaliyetlerinin maddi yahut maddi olmayan desteklerle yürütmektedir.[27] Ülkelerin enerji üretim politikalarında dalgalanmalar olsa da yenilenebilir enerji kaynakları için ayrıcalıklı tutumlarını düzenleyici politikalar/vergi dışı teşvikler ve mali teşvikler olarak iki başlıkta sıralayabiliriz[28]:

Vergi dışı teşvikler:

- Yenilenebilir Enerjide Kota Zorunluluğu Sistemi
- Sabit Fiyat Garantisi
- Lisanssız Üretim Hakkı
- Yenilenebilir Enerji Sertifikaları
- İhale Sistemi

Mali Teşvikler:[29]

- Yatırım veya üretim vergi indirimi; Enerji satımlarında KDV ve diğer vergilerden indirim
- Sermaye sübvansiyonu, hibesi veya iadesi

[25] Farah ve Cima, 2015, s. 520.
[26] Tan, 2010, s. 230.
[27] İbiş, 2018, s. 288.
[28] KPMG, 2016, s. 10 vd. Berksoy ve Akdoğan, 2018, s. 22.
[29] Yurdadoğ ve Tosunoğlu, 2017, s.1.

- Enerji üretimi ödemesi vergi kredileri yatırım teşvikleri, enerji üretim ödemesi, kamu yatırımları, hibe, kredi, indirim ve geri ödemeler gibi teşvikler

1.2. Elektrik Arzı ve Kamu Hizmeti Niteliği

Elektrik arzının idare hukuku boyutunu inceleyeceğimiz bu başlıkta öncelikli olarak kamu hizmetine kısaca değinip ardından elektrik arzının kamu hizmeti niteliği tartışılacaktır. Kamu hizmeti kavramı idare hukuku açısından en temel konulardan olup idarenin faaliyetleri içinde değerlendirilmektedir fakat kesin ve net bir tanımdan bahsetmemiz mümkün değildir. Kamu hizmeti toplumun ortak yararına hizmet eden ihtiyaçların karşılanması için ortaya çıkmıştır.[30] Kamu hizmeti kavramı[31] idare hukukunun iktibas kaynağı Fransız öğretisinden ülkemiz literatürüne geçmiştir.[32] Öğretide görüş birliği bulunmamakla birlikte temel alınan tanımlara baktığımızda kamu hizmeti şöyle ifade edilmiştir: "*toplum için önem kazanmış olan ortak ve genel bir ihtiyacın tatminine yönelik olarak kamu tüzel kişileri veya onların denetimi altında özel kişilerce yürütülen bir faaliyet*"[33] "*yasama organınca kamu hizmeti olarak nitelendirilen idare ya da onun denetim ve gözetimi altında özel kişilerce, kamu yararı amacıyla, toplumun ortak ve genel ihtiyaçlarını tatmin için yapılan faaliyete verilen isim*"[34] "*bir faaliyet, kamu tarafından bizzat ve/veya kamunun gözetim ve denetimi altında bulundurularak sürekli ve düzenli bir biçimde uygulanıp, zaman ve mekânın şartlarına uyum sağlayarak, yöneldiği hukuk süjelerine nesnel ölçütlere uyulmak suretiyle kamusal kaynaklardan finanse edilerek yürütüldüğünde, kamu hizmeti olarak nitelendirilir*."[35]

Kemal Gözler'in Vedel ve Delvolve'den aktardığına göre kamu hizmeti maddi ve organik olmak üzere iki anlam taşımakta; organik anlamda kamu hizmeti teşkilatı bir organizasyonu ifade ederken, maddi anlamda kamu hizmeti kamu yararına yönelik faaliyeti ifade etmektedir.[36] Organik anlamda kamu hizmeti, hizmeti yerine getiren kamu tüzel kişileri, araçlar ve kişiler olarak ön görülse de tam anlamıyla kavramı karşılamamaktadır. [37] Bu kapsamda bir faaliyet ancak kamu yararı amacına hizmet ediyorsa kamu hizmeti olabilecektir.[38] Bunlara ek olarak ilgili hizmet idare tarafından doğrudan yahut idarenin yakın denetim ve gözetiminde gerçekleştirilmelidir.[39]

Anayasa Mahkemesi[40] kamu hizmetini "*En geniş tamına göre kamu hizmeti, devlet ya da diğer kamu tüzel kişileri tarafından ya da bunların gözetim ve denetimleri altında, genel ve ortak gereksinmeleri karşılamak, kamu yararı ya da çıkarını sağlamak için yapılan ve topluma sunulmuş bulunan sürekli ve düzenli etkinliklerdir.*" olarak tanımlamıştır. Danıştay[41] ise "*Kamu hizmeti, umuma arzedilen, sürekli ve kesintisiz bir biçimde işlemesi zorunlu, toplumun genel ve ortak gereksinimlerini karşılamak amacıyla kanunla kurulan idarenin, doğrudan ya da yakın gözetim ve sorumluluğu altında kamusal yetki ve usuller kullanarak yürüttüğü faaliyetlerdir*."

Tanımlardan yola çıktığımızda bir faaliyetin kamu hizmeti olarak değerlendirilmesinde esas iradenin yasama organı olduğunu söylemek yanlış olmayacaktır. Anayasanın 123.maddesi doğrultusunda kamu hizmeti kanunla yahut cumhurbaşkanlığı kararnamesi ile kurulabilecektir. Yukarıdaki bilgiler ışığında kamu hizmetinin hangi usulde gerçekleştirildiğine bakılmaksızın bütün kamu hizmetlerine hâkim olan ilkeler bulunmaktadır.[42] Bu ilkeleri süreklilik, uyarlama, eşitlik, bedelsizlik olarak düşündüğümüzde bir hizmetin kamu hizmeti niteliğini

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[30] Çal, 2008, s. 24.
[31] Kamu hizmeti konusunda yarıntılı bilgi için bkz: Karahanoğullan, O. (2015). Kamu Hizmeti (Kavram ve Hukuksal Rejim), 3. Bası, Turhan Kitabevi.
[32] Derbil, 1950, s. 28.
[33] Gülan, 1988, s.148.
[34] Akyılmaz, Sezginer, Kaya, 2021, s. 558.
[35] Atay, 2018, s.597.
[36] Gözler, 2009, s. 251.
[37] Günday, 2017, s. 330.
[38] Onar, 1966, s. 13.
[39] Balta, 1972, s. 18.
[40] Anayasa Mahkemesi, E: 1994/43, K: 1994/42, KG:09/12/1994, https://normkararlarbilgibankasi.anayasa.gov.tr/ND/1994/42?EsasNo=1994%2F43&KararNo=1994%2F42
[41] DlD, E. 2002/29, K. 2000/59, KT. l 7.04.2000, DD, sy. 104, s. 30. Aktaran: Akyılmaz, Sezginer, Kaya, 2021, s. 558.
[42] Akyılmaz, Sezginer, Kaya, 2021, s. 561.

belirlemede işlevsel olacaktır. Günümüzde kamu hizmetlerinin özel hukuk kişileri eliyle görülmesi yaygınlaşmıştır. Özel hukuk kişileri kamu hizmetini lisans, imtiyaz gibi hukuki süreçlerle görebilecektir.

Elektrik arzının kamu hizmeti niteliğini değerlendirdiğimizde; kamu hizmeti sadece idare tarafından doğrudan gerçekleştirilen hizmetler olmadığını idarenin yakın denetim ve gözetimi ile de gerçekleştirilebileceğini ifade ettik. Elektrik piyasası açısından değerlendiğinde elektrik üretim, iletim ve dağıtım faaliyetleri kapsamında kamuya sunulduğu görülmektedir. Konumuz özelinde üretim faaliyetinin kaynağına odaklandığımız için üretim faaliyeti açısından değerlendirme yapacağız. Elektrik arzı önceleri tekel olarak devlet eliyle gerçekleştirilmekteydi fakat günümüzde özel kişiler eliyle de yürütülmektedir. İlgili hizmetin açıklamalar doğrultusunda kamu hizmeti olduğunda şüphe yoktur.[43] Anayasa Mahkemesi[44] 1994 tarihli kararında daha önceki bir içtihadına atıfta bulunarak "*Elektrik üretimi, iletimi ve dağıtımı ile ilgili etkinlikler kamu hizmetidir. Çünkü bu etkinlikler, kamu yararına dönük, toplumun ortak gereksinmesinin karşılanmasına yönelik, düzenli ve sürekli etkinliklerdir. Nitekim Anayasa Mahkemesi'nin 26.3.1974 günlü, Esas 1973/32, Karar 1974/11 sayılı kararında, "...kişilerin su, elektrik, havagazı gibi ihtiyaçlarının karşılanması önemli kamu hizmetlerindendir." denilerek, elektrik hizmetlerinin kamu hizmeti olduğu açıkça vurgulanmıştır.*" içtihadında bulunmuştur. Karar ile elektrik hizmetinin açıkça kamu hizmeti olduğu ifade edilmiştir. Yine Uyuşmazlık Mahkemesi ve Danıştay da elektrik hizmetini kamu hizmeti olarak görmektedir.[45] Mevzuatımız açısından değerlendirdiğimizde ise lisanssız elektrik üretimini ari tuttuğumuzda, enerji nakil hatları, yenilenebilir enerji kaynakları için Cumhurbaşkanı kararıyla acele kamulaştırma yapılabilmektedir. Bu durum da yine elektrik hizmetinin yasa koyucu nazarında kamu hizmeti olduğuna işaret etmektedir. Kamu hizmetinin görülme usullerinden olan yap işlet devret modeli ile görülmesi elektrik arzı için de ön görülmüştür.[46] Mezkûr düzenleme ile işletme hakkı devir yöntemi, yani mülkiyet değil hizmetin işletme hakkı devredilmektedir.[47] Enerji arz yöntemleri özellikle teknolojinin gelişmesi ile çeşitlilik kazanmış, arzın özel kişiler eliyle yürütülmesi bu hususu hızlandırmıştır. Teknolojinin gelişimi ile ileride fosil yakıt kaynaklı enerji arzı yerini tamamen yenilebilir enerji kaynaklarına bırakacaktır.[48] Her ne kadar çevreye zararı olamadığı iletilse de üretim ve kurulum alanlarına zarar verebilmektedir.[49] Bu kapsamda idare, hidroelektrik santrallerin çevreye zararı[50] özelinde hassas ekosisteme sahip alanlarda hidroelektrik santral kurulumuna izin vermemeli kendisi de kurmamalıdır.[51]

Elektrik arzı faaliyetinin kamu hizmeti olarak değerlendirilmesi için kamu yararı, toplumun ihtiyaçlarını karşılamak amacında olması bu bağlamda idare ile taahhüt sağlanmalıdır. Bu durum ise enerji piyasasında denetim ve gözetimi belirli standartlarda hizmet sunumunu gerektirmektedir. İdare bu faaliyeti ise EPDK ile yapmaktadır. Kamu hizmeti yerine getirilirken idarenin sahip olduğu kamu gücü elektrik hizmeti bağlamında da kendini göstermektedir. Hizmeti gerçekleştiren özel kişiler olsa da kamulaştırma yetkisi veya idarenin elektrik arz ücretlerini tek yanlı iradesi ile belirleyebilmesi yine hizmetin kamu hizmeti olmasına işaret eder. Kamu hizmeti için öğretide ön görülen *bağışık kılınma* unsuru ile açıklanabilecektir. Bu unsura göre kamu hizmetinin üretim alanının zorlukları devlet tarafından bağışık kılınarak üstlenilmektedir.[52] Bu kapsamda mutual bir süreçten bahsetmek mümkün olacaktır hizmeti gerçekleştiren kişi gelir elde ederken idare de hizmetin sürdürülebilirliğini garanti edecektir.[53]

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[43] Elektrik piyasasının iktisadi kamu hizmeti olduğu hususu öğretide uzlaşı ile kabul edilmiştir. (Tan, 2006, s. 647.) Ayrancı, 2010, s. 47.

[44] Anayasa Mahkemesi, E: 1994/43, K: 1994/42, KG:09/12/1994, https://normkararlarbilgibankasi.anayasa.gov.tr/ND/1994/42?EsasNo=1994%2F43&KararNo=1994%2F42

[45] Uyuşmazlık Mahkemesi, E. 1999/48, K. 1999/47, T. 6.12.1999; Uyuşmazlık Mahkemesi, E. 1998/4, K. 1998/6, T. 9.2.1998; Uyuşmazlık Mahkemesi, E. 2000/6, K. 2000/5, T. 27.3.2000) Danıştay 10. Daire, E. 1991/1, K. 1993/1752, T. 29.4.1993; Danıştay İDDGK, E. 1996/79, K. 1996/83, T. 3.10.1996. Aktaran: Ergün, 2010, s. 186.

[46] 19 Temmuz 1997 tarih ve 23054 sayılı Resmi Gazetede yayımlanan 4283 sayılı Yap-İşlet Modeli İle Elektrik Enerjisi Üretim Tesislerinin Kurulması ve İşletilmesi İle Enerji Satışının Düzenlenmesi Hakkında Kanun.

[47] Ayanoğlu, 2007, s. 6.

[48] Çakmak, 2018, s.17.

[49] Şenpınar ve Gençoğlu, 2006, s. 53.

[50] Güneş, 2014, s. 38 vd.

[51] Çakmak, 2018, s. 200.

[52] Karahanoğullan, (2015), s.54.

[53] Özkaya Özlüer, 2022, s. 288.

Elektrik hizmetinin kamu hizmeti olduğu konusunda konuyu daha ayrıntılı olarak incelemek için bkz: Ergün.

1.3. Kamu Yararı

Kamu yararı kavramının idare hukuku açısından kamu hizmetinin maddi boyutunu oluşturduğu yukarıda dile getirmiştirk. Kamu yararı idare hukukunun en yaygın kullanılan kavramlarından olmasına rağmen net bir tanıma kavuşamamış, öznel, bulanık olduğu muhtevasının belirlenemediği ifade edilmiştir.[54] Buna rağmen kamu yararı aksi kanıtlanmadığı sürece idarenin her faaliyetinin gayesi olduğu da ifade edilmiştir.[55] Bu tartışmalara girmeden konumuz özelinde yenilebilir enerji kaynaklarının tercih edilmesindeki maddi külfete katlanma hali kamu yararı kapsamında irdelenecektir.

Elektrik enerjisi üretim, iletim ve dağıtım boyutlarıyla üç ana konuda incelenmiştir. Bu bağlamda belirlenecek politikalar üretime, iletime, dağıtıma göre farklılık arz edecektir. Şöyle ki çevreye yarattığı etki bakımından incelendiğinde arz açısından yenilebilir kaynaklardan elde edilmesi politikası güdülürken, dağıtımda ise kademeli fiyatlandırma politikası ile tüketimin azaltılması politikası güdülebilmektedir. Kısaca politikaları hükümetlerin geleceğe yönelik önlemleri olarak ifade edilebilecektir.[56] Enerji arzı özelinde kaynakların doğru planlanması temel enerji politikalarını oluşturmaktadır.[57] Enerji politikalarını belirleyen temel etkenler enerji güvenliği ve çevresel faktörlerdir.[58] Enerji politikasını belirleyen bu iki etken kimi zaman çatışabilecektir şöyle ki enerji güvenliği kapsamında kömürden elde edilen ucuz ve sürekli elektrik hizmeti sunulması çevreci olmayacaktır. Bu durumda bir tercihte bulunulması gerekecektir, mevzubahis durumu somutlaştırdığımızda Avrupa Birliği 2050 yılına kadar karbon nötr hedefli enerji politikasına sahiptir bu bağlamda enerji kaynaklarında çevre ve iklim değişikliğine yönelik politikalar kapsamında yenilenebilir enerji kaynaklarına yönelim söz konusudur. Fakat Rusya-Ukrayna savaşı ile Avrupa Birliğinin Uluslararası Enerji Ajansı'nın (IEA) *kömür 2022* raporuna göre kömüre yöneldiğini görmek mümkündür.[59] Somut örnekte enerji güvenliği tercih edilmiş çevre iklim değişikliği politikaları ötelenmiştir. Enerji politikalarını belirlemede çok fazla parametre olmasına rağmen yenilenebilir enerji kaynakları için maddi külfete katlanmak toplumun yararına mıdır? Anayasa Mahkemesi kararları incelendiğinde elektrik hizmetleri arasında sıralama yapıldığı görülmektedir. Mahkeme elektrik hizmeti için önemli, stratejik öneme sahip, temel gibi sınıflandırmalarda bulunmuştur.[60] Bu bağlamda enerji kavramı egemenlik ile bağlantılı görülmüş, enerji olmadan devletin temel amaç ve görevlerini yerine getirmesinde aksamalar olacak; temel hak ve özgürlükleri, sosyal devlet ilkesi, adalet ilkesinin gerçekleşmesi aksayacaktır.[61] Netice olarak enerji arzının sürekli ve güvenli şekilde vatandaşlara sunulması temel amaç olarak görülmüş; kamu yararı boyutu geniş anlamda değerlendirilmiştir. Toplumsal yaşamın sürdürülmesi ile doğrudan ilgili olan enerji arzının çeşitli kaynaklardan elde edilebileceğini ifade etmiştik idare bu tercihini kullanırken birçok etkene dikkat edeceğini de ifade ettik enerji arzının kamu hizmeti niteliği itibariyle bu etkenlerden biri de kamu yararıdır.

Konumuz özelinde maddi külfete katlanmanın kamu yararı ile ilişki üzerine düşündüğümüzde kamu yararı her zaman ekonomik olanı mı tercih etmeli paradoksu ile karşılaşırız. Hukuk ekonomi ilişkisi kapsamında değerlendirirsek her zaman idarenin kamu adına en karlı olanı seçmesi gerekir. Fakat hukuka ekonomik yaklaşım ile baktığımızda verimlilik ile yanıtlanmaktadır.[62] Bu bağlamda ortaya ekonomik kamu yararı çıkacaktır ki idare hukuku kapsamında verimlilik ile benzeşen bir kavramdır. Verimlilik kavramı klasik anlamda refah ekonomisine dayanmakta, refah ekonomisi ise eylemlerin sonuçlarının refaha etkisi ile ilgilenmektedir.[63] Açıklamaya göre verimlilik, toplam kar ve toplam maliyet arsındaki ilişki ifade

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[54] Duran, 1982, s. 25.
[55] Akıllıoğlu, 1988, s. 11.
[56] Keleş/ Hamamcı/ Çoban, 2009, s.336.
[57] Soydal, Mızrak, Çetinkaya, 2012, s.130.
[58] Şekercioğlu, Yılmaz, 2012, s.234.
[59] IEA, 2022, rapora göre küresel bazda kömür tüketimi %1.2 artarken Avrupa Birliğinde 478 milyon ton kömür tüketimi ile %6.5 artmıştır.
[60] Anayasa Mahkemesi, E: 1973/32, K: 1974/11, KG: 26/3/1974: … "Kişilerin *su, elektrik, havagazı gibi ihtiyaçlarının karşılanması önemli kamu hizmetlerindendir.*" …
https://normkararlarbilgibankasi.anayasa.gov.tr/ND/1974/11?EsasNo=1973%2F32&KararNo=1974%2F11
Anayasa Mahkemesi, E.1994/49, K.1994/45-2, KG: 07/07/1994: … "*Telekomünikasyon, elektrik üretim, iletim ve dağıtım gibi stratejik önemi olan alanlara yabancıların girmesinin ötesinde, egemen olması, güvenlik, bağımsızlık ve ekonomik yönlerden çok sakıncalı olabilir . Çünkü, bu tür kamu hizmetleri ülke güvenliği ile çok yakından ilgilidir.*" …
https://www.resmigazete.gov.tr/arsiv/22047.pdf
[61] Yayla, 2013, s. 30 vd.
[62] Uyanık, 2013, s. 45.
[63] Mathis, 2009, s. 31.

edilebilecektir. İdarenin teşkili verimlilik temelindedir, toplumsal faydası maliyetleri aşıyorsa etkin kurumlar inşa edilecektir.[64] Fakat kar odaklı yaklaşım da adalet perspektifi ile çelişebilmektedir. Şöyle ki sosyal devlet ilkesi kapsamında yapılan dar gelirlilere yardım veya getirisi rasyonel olmayan krediler ile sosyal konut projeleri şüphesiz verimlilikle bağdaşmaz fakat kamu yararı olduğu ortadır.[65] Hukuk ve ekonomi politikaların özelinde adalet ve verimlilik amaçları arasında gelgitlerin oluştuğu kavram ekonomik kamu yararı olarak ifade edilebilir.[66] Bu bağlamda kamu yararı sadece ekonomik verimlilik temelinde olacağı durumlar ile toplumsal fayda temelinde de olabilecektir. Toplumsal fayda temelinde idare piyasaya müdahale edebilecektir. Sonuç olarak ekonomik kamu yararı verimlilik ve adalet kavramları arasındaki dengede oluşacaktır. Kısaca ifade etmek gerekirse ekonomik veçheden bakarsak temel gaye olarak verimlilik ile hukuk veçhesinden bakarsak adaletin sağlanması temel gaye olacaktır ki idare hukukunun temel konularından olan *kamu yararı* çok boyutlu bir kavramdır. Bu sebepledir ki baktığımız açıdan kamu yararı kavramı boyut değiştirebilecek bakış açısına göre çatışma hali görülecektir. Şöyle ki kamu yararına adalet temelli yaklaştığımızda kamu yararının sosyal dağıtıcı adalet düşüncesine dayanması ekonomik olarak verimli olmayan tercihlerin seçilmesini sağlamaktadır.

Kamu yararı, yukarıda kamu hizmetinin maddi görünümü olarak ifade edilmişti. Kamu yararı idare hukuku anlamında idari işlemlerin genel ve nihai amacı olarak ifade edilir.[67] Kamu yararı idare hukuku için referans değerlerden biri olup bir hukukilik denetiminin özde denetiminin teminatıdır.[68] İdarenin işlemlerini eylemlerini gerçekleştirirken aslında hukuki zemine oturtmasını sağlayan araç olarak ifade edebiliriz. Her ne kadar çok boyutlu olsa da net bir tanımı olmasa da kamu yararı idarenin meşru zeminidir. Bu bağlamda idare faaliyetlerinde işlemlerinde kamu yararı amacıyla hareket edecektir. Özendirme ve destekleme faaliyetleri de idarenin eylemlerinden olduğundan kamu yararını amaç edinmesi kaçınılmazdır. Özendirme ve destekleme faaliyetleri için amaçlanacak kamu yararı ekonomik kamu yararıdır. Şöyle ki kamu yatırımlarında israfa engel olmak ve verimli neticeler almak ancak ekonomik kamu yararı ile rasyonel kararlarla mümkündür.[69] 1982 Anayasasının 166. Maddesi incelendiğinde kaynakların verimli kullanılmasını planlamak yine bu kapsamda idareye verilen bir görevdir. Mezkûr hükme göre geleceğe yönelik kalkınma planlarının yapılması düzenlenmiştir. Bu palanlar yapılırken hangi hususlara dikkat edileceği ve yatırımlarda kamu yararı gözetileceği açıkça belirtilmiştir. Bu kapsamda yatırım planları kamu yararı ile kaynakların verimli kullanılması amacı ile oluşturulacaktır. Planlama işlemlerinin hukuki nitelik konusunda sarih bir açıklama yapmak mümkün olmayıp Danıştay DDK'nin 1973 tarihli kararı ile idari işlem olarak saymaması iptal davasına konu etmemesi belirsizliğe itmiştir.[70] Fakat Anayasa hükmünde yer alan *yatırım ve istihdamı geliştirici verimlilik* amaçlar ile değerlendirildiğinde ekonomik kamu yararı kavramı ile bağdaşmaktadır. Yapılacak yarar analizi ile yapılan bir plan ekonomik kamu yararı temeline oturacak bu sayede de planlama faaliyetleri bir hukuki rejime sahip olacak ve yargısal argüman ortaya çıkacaktır.[71]

1.4. Gelecek Nesillerin Hakkı: Çevre Hakkı

İnsan hakları en genel ifadesiyle insanın insan olmasından kaynaklı madden manen gelişimi gayesindeki hakların bütünü olarak düşünülebilir. İnsan haklarının gelişimi çeşitli tarihsel dönemlere göre kuşaklara ayrılmıştır, yapılan bu tasniflerde neden sonuç ilişkisine göre insan hakları yeni boyutlar ile değerlendirilmiş, gelişmiş ve kapsayıcı olmuştur. Şöyle ki birinci kuşak haklar klasik haklar kişi özgürlüğü ve siyasal hakları barındırırken ikinci kuşak haklar ise sosyal haklar olarak da ifade edilen çalışma, sendika kurma hakkı gibi hakları ifade etmektedir. Üçüncü kuşak haklar ise dayanışma hakları olarak anılan bu grup ise hem bireyim hem de devletin ortak çabasıyla gerçekleştirilen çevre, barış hakkı gibi insan haklarıdır.[72] İnsan haklarını kuşaklara ayrılması sebebi birbirinden ayrı düşünülemez, çevre hakkı özelinde değerlendirdiğimizde özünde yaşam hakkı ve insanın maddi manevi varlığını geliştirme hakkı ile bağlantılı olduğunu tespit edebiliriz, ez cümle insan hakları birbirinden bağımsız olarak kuşaklara ayrılmamış kümülatif olarak kuşaklar halinde gelişmiş ve birbirine kaynaklık ederek gelişim göstermiştir. İnsan hakları bu bütüncül yapısıyla birlikte

[64] Uyanık, 2013, s. 51.
[65] Tan, 2015, s. 32.
[66] Uyanık, 2013, s. 61.
[67] Akyılmaz, Sezginer, Kaya, 2021, s. 435.
[68] Güran, 2008, s.9.
[69] Uyanık, 2013, 103.
[70] Duran, 1975, s. 21.
[71] Uyanık, 2013, s. 104.
[72] Ayrıntılı olarak incelemek için bkz: Akbaba, 2016.

evrensel, özgürlükçü, eşit nitelikleri haizdir. Bu bağlamda evrensel olması sebebiyle kültür veya siyasi sisteme göre farklılık göstermezler.[73]

Çevre sorunlarının artması ve insanların doğrudan veya dolaylı yoldan etkilenmesi çevre hakkının bir insan hakkı olduğuna ilişkin bilinci oluşturmuştur. İnsanlığı etkileyen bu tehditlere karşı tedbir alınması fikri gündeme gelmiş, Çevre hakkı kavramı 1972 tarihli Birleşmiş Milletler Çevre Konferansı Stocholm Bildirgesi ile hukuki metinlerde kendisine yer bulmuş; 1992 Rio Konferansı ile devamı gelmiştir. Anayasalarda da sağlıklı ve dengeli bir çevrenin halk olarak yer almaya başlaması ülkeden ülkeye farklılık gösterse de pozitif hukuk açısından düzenlendiğini göstermektedir.[74] Çevre hakkının konusu çevre; çevrenin korunması, geliştirilmesi olarak ifade edilebilir.[75] Bu kapsamda çevre, insan veya canlı varlıklar özelinde bir süreç dahilinde yahut derhal etki gösterebilecek fiziksel, kimyasal, biyolojik ve toplumsal etkenlerin toplamıdır.[76] Çevre hakkının konusunu yaşamın sürdürüldüğü biyosfer ve bu alanı oluşturan elementlerin tamamı olarak ifade edilebilir.[77] Çevrenin korunması ve iyileştirilmesi hakkın yerine getirilmesinde negatif ve pozitif iki temel fonksiyona işaret etmektedir.[78] Çevre hakkını diğer haklardan ayıran bir durum da hak ve ödev kavramlarının iç içe geçmiş olması neticesinde yararlanıcı ve yükümlüleri hem hak hem de ödev sahibi olabilmesidir.[79] Hakkın öznesi o hakkın sahibi yahut yararlanıcısı olarak ifade edilir.[80]

Çevre hakkının sahiplerini/öznelerini bireyler, topluluklar, gelecek nesiller ve devlet olarak ifade etmek mümkündür.[81] Çevre hakkının diğer haklardan farkı, günümüz insanlarının gelecek nesillere karşı sorumluluğu ve iki nesil arasındaki dayanışmayı barındırmasıdır.[82] Bu çerçevede sağlıklı bir çevrede yaşamak mekânsal değil zaman anlamında da insanlar *kuşaklar* arasındaki dayanışmayı gösterir.[83] İnsanlar nesiller arasındaki dayanışma ile gelecek nesillerin de refah ve esenliğini koruma gayesinde olmalıdır.[84] Bu doğrultuda çevrenin barındırdığı ekolojik işleyiş ve kondisyonlar insan yaşamına en elverişli şekilde gelecek nesillere miras bırakılmalıdır. Henüz doğmamış kişilere bu hakkın sahibi gözüyle bakılması alışılageldik olmasa da bu durum hakkın özgü yapısı ile yanı dayanışma hakkı olarak nitelendirilmesi ile açıklanabilir.[85] Hukuki olarak bir hakka sahip olabilmek tam ve sağ doğum ile mümkün olmasına rağmen gelecek nesillere yaşama elverişli çevre devretme ödevi sadece ahlaki olarak değerlendirilmemeli bunun yanında hukuki yükümlülük olacak şekilde genişletmek dayanışma hakkı kapsamındaki çevre hakkının ruhuna uygun olacaktır.[86]

Çevre hakkının gelecek nesillere dair dayanışma hakkı olmasının yanında klasik haklar olarak ifade edilen haklar ile sıkı ilişki içindedir, insanın en temel hakkı olan yaşam hakkının mekânsal boyutunu yansıtan çevre hakkının korunmadığı bir hukuk düzeninde diğer hakların korunmasından da bahsetmek mümkün olmayacaktır. Çevre sorunlarının geldiği son radde düşünüldüğünde gelecek nesillerin sağlıklı bir çevrede yaşaması ancak küresel ve sağlam bir irade ile mümkündür. Üçüncü kuşak hakların niteliği düşünüldüğünde çevrenin korunması devletler ve bireylerin el birliği ile mümkün olabilecektir. Konumuz özelinde çevre hakkının gelecek nesillere dair özelliği irdelenmiş olup konu burada sonlandırılacaktır.

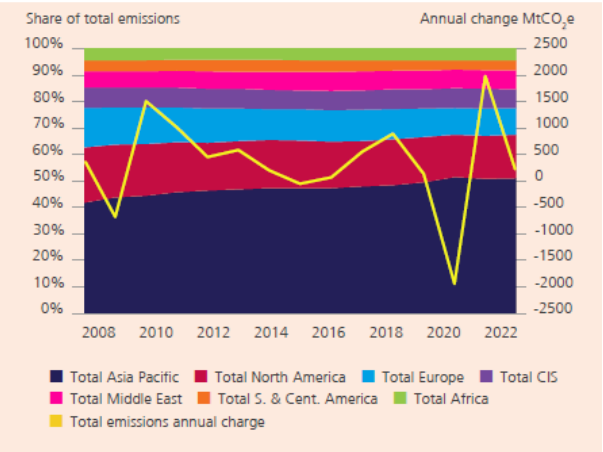
SONUÇ

Elektrik arzı kamu hizmeti olarak ifade edilmiştir, yine mezkur kamu hizmeti maddi anlamda irdelendiğinde yapılan hizmetin kamu yararı amacına özgülenmesi gerekmektedir. Fakat yenilebilir enerjiye sağlanan avantajlı tutum kamuya maddi külfete neden olmaktadır. Bu maddi külfete katlanmak ise bugünün toplumunun yarının toplumuna olan borcudur. Bunu ancak çevre hakkı ile temellendirebilmekteyiz. İnsan hakları açısından

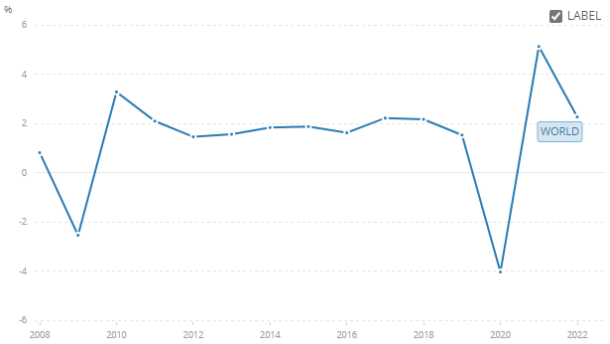
[73] Çotuksöken, 2002, s. 32.
[74] Kaboğlu/ Özalp, 2021, s. 50. Turgut, 2001, s. 613 vd.
[75] Hamamcı, 1983, s. 244.
[76] Keleş/ Ertan, 2002, s. 81.
[77] Kaboğlu/ Özalp, 2021, s.91. Keleş/ Ertan, 2002, s. 85.
[78] Özdek, 1993, s. 104.
[79] Keleş/ Ertan, 2002, s. 83.
[80] Gözler, 2020, s. 527.
[81] Özdek, 1993, s. 107. Keleş/ Ertan, 2002, s. 83.
[82] Dadak, 2015, s. 316.
[83] Kaboğlu/ Özalp, 2021, s. 88.
[84] Weiss, 1990, s. 200.
[85] Güneş, 2021, s. 154.
[86] Özdek, 1993, s. 110.

değerlendiğinde üçüncü nesil insan hakları kapsamında çevre hakkı gelecek nesillerin hakkı olarak görülmüştür. Bu bağlamda yenilenebilir enerji kaynaklarına maddi külfet özelinde bugün kamu yararına hizmet etmese de yarının kamu yararına hizmet etmektedir. Fakat geleceğe yapılan bu yatırımdan kesin sonuç alacağımızı iddia edememekteyiz, gelecek nesillerin faydası açısından hiçbir şey yapmamaktansa bu kapsamda yenilenebilir enerji kaynakları için sağlanan teşvik ve avantajlı tutum kabul edilebilir olarak değerlendirilmektedir. Kamu yararının gerçeklemesinde özel bir görünüm olan ekonomik kamu yararı kavramı adalet ve verimlik arasındaki dengeden doğmaktadır. İdarenin bazı faaliyetleri verimli/karlı olmasa da dağıtıcı adalet anlayışı ve sosyal devlet ilkesi gereği kamu yararı taşıyabilmektedir. Bu bağlamda özendirme; planlama faaliyetleri ekonomik kamu yararı kapsamında değerlendirilebilecektir. Devletin planlama müdahale faaliyeti toplumsal fayda açısından sadece piyasa aksaklıkları olduğu hallerde değil toplumsal fayda ölçütünün dağıtıma-paylaşılmasına ilişkin hedefler içerdiği hallerde piyasa verimli hale gelmesine rağmen toplumsal faydaya haiz olmayabilir. Ancak bu durum gelir/fayda açısından adil sonuçlar içermeyebilir. Bu bağlamda piyasa mekanizması üretim açısından verimli ama kamu yararı içermeyebilir. Somutlaştırmak gerekirse özendirme ve destekleme faaliyetleri bugün için toplumsal fayda içermese de ileride oluşacak piyasa ve koşullar için kamu yararı amacına ulaşabilir.

Çevre sorunlarının neticelerinden küresel ısınma ve iklim krizi bugünlerde insanlığı tehdit eden en büyük tehlike olarak görülmekte fakat insan hakları kapsamında çözüm üretilmesinde ciddi sıkıntılar oluşmaktadır. Artık küresel ısınmanın yahut iklim krizinin önüne geçmenin bile mümkün olmadığı iddia edilmektedir.[87] Her ne kadar zor bir çaba olarak görünse de yaşanabilir bir çevre hakkının gelecek nesillere bırakılması ahlaki bir görevdir. Bu kapsamda çevre hakkı ancak küresel mücadele ile korunabilecektir. Tablo 6 ve Tablo 7 birlikte incelendiğinde toplam emisyonun yıllık değişimi ile ekonomik büyümenin doğru orantıda olduğu görülecektir, buradan çıkan sonuç ise ancak çevreye saygılı, sürdürülebilir büyüme planı ile çevre hakkının korunabileceğidir. Emisyon değerleri ve ekonomik büyümenin Covid-19 pandemisi döneminde en büyük düşüşü yaşadığı yine tablolardan görülmektedir. Ez cümle ekonominin motoru enerjiden geçmektedir, şu hâlde çevreye saygılı büyüme ve yatırım modelleri ile ancak çevre sorunları aşılabilecektir. Sonuç olarak geleceğe yönelik yatırımların çevre hakkı kapsamında değerlendirilmesi bu doğrultuda üstlenilecek maddi külfetin ekonomik kamu yararını amaçlaması gerekmektedir.



Tablo 6: Dünya geneli emisyon değerleri, Kaynak: BP, 2022.



Tablo 7: Kişi başına GSYİH büyümesi, Kaynak: Dünya Bankası

[87] https://www.ntv.com.tr/galeri/dunya/bilim-insanlarindan-kuresel-isinma-uyarisi-en-iyi-senaryoda-bile-felaketlerin-onlenmesi-imkansiz,ze5aAlUDeEanow8mbtHaOg

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SÜRDÜRÜLEBİLİR ULAŞIM POLİTİKALARININ İKLİM DEĞİŞİKLİĞİ İLE MÜCADELEDEKİ ROLÜ

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ÖZET

İklim değişikliğinin etkileri her geçen gün şiddetini artırarak daha belirgin hale gelmektedir. Tüketim iştahındaki sürekli artış, üretim faaliyetlerinin kapsamını genişletmekte ve bu durum daha çok karbon salınımını beraberinde getirmektedir. Sorunların daha yakından hissedilir bir hal alması iklim değişikliği ile mücadeleye yönelik ulusal ve uluslararası gayretleri de artırmıştır. 20.yy'ın sonları ve 21.yy'ın başlarında popülerlik kazanan yönetişim, sürdürülebilir kalkınma gibi yeni kavramlar ve yaklaşımlar iklim değişikliği ile mücadele politikalarına da sirayet etmiştir. Birçok paydaşın bir araya gelmesiyle katılımcı bir anlayışı benimseyen yönetişim, iklim değişikliği ile mücadelede aktörlerin önemini pekiştirmiştir. Öte yandan sürdürülebilir kalkınma ise Birleşmiş Milletlerin on yedi temel hedef üzerinden inşa ettiği, bugünün ihtiyaçlarını karşılarken gelecek nesilleri de düşünmenin gerekliliğini vurgulayan bütüncül bir yaklaşımdır. Kaynakların sınırlı olması, iklim değişikliğinin de etkileriyle birleştiğinde gelecek için tablo karamsar bir hal almakta ve durum zamanla daha kötüye gitmektedir. İnsan faaliyetleri iklim değişikliğinin olumsuz etkilerinin artışına neden olurken, iklim değişikliği de insan faaliyetlerini olumsuz yönde etkilemektedir. Sürdürülebilir kalkınma ilkeleri doğrultusunda yaşam standartlarında küresel iyileştirmeler hedeflenirken iklim değişikliğinin de hemen her aşamada göz önünde bulundurulması gerekmektedir. Bu çalışmada sürdürülebilirlik ve iklim değişikliği ilişkisi ulaşım politikaları üzerinden kurulmuştur. Ulaşım faaliyetleri, endüstriyel üretimle birlikte karbon salınımının en büyük sebepleri arasında gelmektedir. Nüfusun artması dünya genelinde hareketliliği artırmakta, daha çok ulaşım faaliyeti daha çok karbon salınımı anlamını taşımaktadır. Bu nedenle ulaşımda etkin ve uygulanabilir politikaların benimsenmesi hem enerji kaynaklarının verimli kullanımına hem de iklim değişikliği ile mücadeleye doğrudan katkı sağlayacaktır. Bu çalışmadaki amaç yenilikçi, iklim dostu, sürdürülebilir ulaşım politikalarını ve uygulamalarını çeşitli örneklerle ele alarak iklim değişikliği ile mücadeledeki rolün ortaya konmasıdır. Bu doğrultuda sürdürülebilir ulaşım ulusal ve uluslararası politika belgeleri ışığında; çekme-itme politikaları, enerji alternatifleri, akıllı ulaşım sistemleri şeklinde üç temel başlıkta ele alınmıştır. Sayısal verilerle ulaşım ve iklim değişikliği ilişkisi desteklenmiş, başarılı uygulama örnekleriyle de konunun pekiştirilmesi hedeflenmiştir.

Anahtar Kelimeler: Sürdürülebilir ulaşım, iklim değişikliği, karbon salınımı

THE ROLE OF SUSTAINABLE TRANSPORTATION POLICIES IN COMBATING CLIMATE CHANGE

ABSTRACT

The effects of climate change are becoming increasingly pronounced day by day, intensifying and becoming more evident. The continuous increase in consumption appetite expands the scope of production activities, leading to a higher level of carbon emissions. The heightened awareness of these issues has increased national and international efforts to combat climate change. Governance, a concept that gained popularity in the late 20th century and early 21st century, along with new concepts and approaches such as sustainable development, has also influenced policies addressing climate change. Governance, embracing a participatory understanding through the collaboration of various stakeholders, has reinforced the importance of actors in the fight against climate change. On the other hand, sustainable development is a holistic approach emphasized by the United Nations, built upon seventeen fundamental goals, highlighting the necessity of considering the needs of future generations while meeting the current ones. The limited availability of resources, combined with the effects of climate change, paints a pessimistic picture for the future, worsening over time. Human activities contribute

to the increase in the negative impacts of climate change, while climate change also adversely affects human activities. In pursuit of improvements in global living standards in line with sustainable development principles, it is crucial to consider climate change at every stage. In this study, the relationship between sustainability and climate change is established through transportation policies. Transportation activities, along with industrial production, rank among the major causes of carbon emissions. The increase in population worldwide leads to increased mobility, and more transportation activities imply more carbon emissions. Therefore, adopting effective and implementable transportation policies contributes directly to efficient energy use and the fight against climate change. The aim of this study is to highlight the role of innovative, climate-friendly, sustainable transportation policies and practices in combating climate change through various examples. In this context, sustainable transportation is addressed under three main headings based on national and international policy documents: pull-push policies, energy alternatives, and smart transportation systems. The relationship between transportation and climate change is supported by numerical data, and successful application examples aim to reinforce the subject.

Keywords: Sustainable transportation, climate change, carbon emissions

GİRİŞ

İnsan faaliyetleri sonucu yerkürenin ısı dengesini bozan küresel ısınma, iklim değişikliği sürecinin giderek hızlanmasına neden olmaktadır. İklimin ortalama değişkenlerinde yaşanan farklılıklar olarak bildiğimiz iklim değişikliği ile mücadele günümüzün öncelikli konularındandır. Uluslararası kuruluşların çalışmalarına konu olması ve bu hususta önemli fonlar ayrılması farkındalığın artışında önemli rol oynamıştır. İklim değişikliği ile mücadelenin en önemli yapı taşlarından biri sürdürülebilirliktir. En kısa anlamıyla faaliyetlerin devamlılığı anlamına gelen sürdürülebilirlik özellikle 20.yüzyıl sonlarından başlayarak popülerliğini artırmıştır. Sürdürülebilirlik, küresel örgütlerin program ve politikalarında sürdürülebilir kalkınma halini alarak çok boyutlu bir yapıya dönüşmüştür.

Birçok bileşeni bulunan sürdürülebilir kalkınma; insanların ve doğanın hem bugünü hem de yarınları ile ilgilenmektedir. İhtiyaçların karşılanması, hizmetlere erişim gibi hususlarda ilkeli yaklaşımlar benimsenirken doğanın korunmasının da her zaman öncelikler arasında olduğu politikalar bütünüdür. Sürdürülebilir kalkınmanın tam manasıyla sağlanabilmesi için tüm sektörlerde entegre iyileştirmelerin yaşanması gerekmektedir. Sürdürülebilir tarımdan sürdürülebilir enerjiye, sürdürülebilir turizmden sürdürülebilir ulaşıma; sürdürülebilirlik bilincinin her alana nüfuz etmesi kalkınmanın sağlanmasında kilit rol oynamaktadır

Bu çalışmada sürdürülebilirlik ulaşım boyutu üzerinden ele alınacaktır. Çalışmanın omurgasını ulaşım faaliyetleri ve iklim değişikliği ilişkisi oluşturmaktadır. Sera gazı emisyonlarının artması, çevrenin kirlenmesi, gürültü, trafik sıkışıklıkları gibi insanlar ve doğa için birçok sorun barındıran ulaşım faaliyetlerinin iklim değişikliği üzerindeki etkileri incelenip; akabindeyse bu olumsuzluklarla mücadele noktasında sürdürülebilir ulaşım politikalarının önemi vurgulanacaktır.

İklim değişikliği ve sürdürülebilir ulaşım ilişkisini ele alan bu çalışmada yöntem olarak literatür taraması kullanılacaktır. Ulusal ve uluslararası politika programları incelenecek, sayısal veriler üzerinden ulaşım faaliyetlerinin sera gazı salınımlarını tetikleyerek iklim değişikliği üzerinde yarattığı olumsuz etki ortaya konmaya çalışılacaktır.

İKLİM DEĞİŞİKLİĞİ VE ULAŞIM FAALİYETLERİ İLİŞKİSİ

İklim değişikliği, iklimin belirli bir süre zarfında ortalama değerlerinde yaşanan değişimler, beklenmedik hava olayları ve tüm bunlardan etkilenerek ekosistem üzerinde gerçekleşen olumsuzluklar bütünü olarak tanımlanabilir. İklim değişikliği yalnızca havaların ısınıp soğuması ya da düzensiz yağış rejimlerinden ibaret bir sorun değildir. Gıda güvenliği, kitlesel göçler, kuraklık, ormansızlaşma, enerji krizleri gibi birçok alanda; sosyal, ekonomik ve çevresel sorunların habercisidir. İklim değişikliğinin günübirlik bir problem olmamasından da hareketle, atılacak adımların ve alınacak tedbirlerin orta ve uzun vadeli planlanması gerekmektedir.

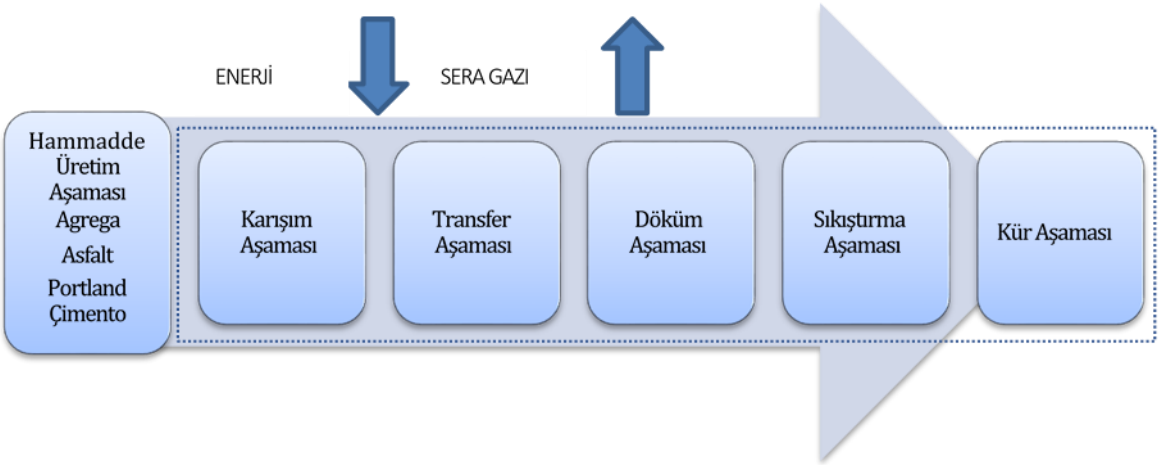
Dünya genelinde hakim olan nüfus artış eğilimi, üretim faaliyetlerinin ve küresel hareketliliğin artışına neden olmaktadır. Bu durum sera gazı salınımlarının daha çok artması ve iklim değişikliğinin etkilerinin daha belirgin hale gelmesi anlamını taşımaktadır. İklim değişikliği ile mücadele edebilmek için çok yönlü ve uygulanabilir

politikalar geliştirilmek durumundadır. Sektörel sınırlar çerçevesinde düşünmek, yüksek maliyetli projelerin kusursuz işleyişine olan inanç gibi tekil yaklaşımlar sorunların artarak büyümesine neden olmaktadır (Buldurur, 2018). Bütüncül politikalar inşa ederek, sektör ve bölge gibi farklılıkların kendi içindeki özgün dinamikleriyle zemin güçlendirilmelidir. Politikaların, planların ve uygulamaların etkin sonuçlar verebilmesi adına ulusal ve uluslararası mekanizmalarla desteklenmeleri zaruridir.

İklim değişikliği ile mücadelenin temelinde 'azaltma ve uyum' şeklinde iki temel yaklaşım yatmaktadır. Azaltma politikaları, olası etkilerin mümkün mertebe engellenebilmesi ya da sürecin yavaşlatılabilmesi adına gerekli tedbirlerin alınmasıdır. Fosil yakıt kullanımın sınırlandırılması, bazı canlı türlerinin avlanmalarının tümden yasaklanması azaltma önlemlerine örnek olarak gösterilebilir. Uyum politikaları ise, iklim değişikliğinin meydana getirebileceği etkilere karşı toplumsal ve iktisadi düzeyde hazırlıklı olmaya yönelik çalışmalardır. Suların yükselme riskine karşın kıyılara bentler yapılması, daha az suya ihtiyaç duyan bitkilerin geliştirilmesi uyum politikalarına örnek olarak gösterilebilir (Doğan ve Tüzer, 2011).

İklim değişikliğini birçok etmenle birlikte ele almak mümkündür. Ulaşım faaliyetleri iklim değişikliğini tetikleyen en önemli nedenlerin arasında gösterilebilir. Gerek hemen hemen her sektörle ilişkili olması, gerekse insanlığın temel ihtiyaçlarına erişiminde sahip olduğu pay ulaşım faaliyetlerinin önemini pekiştirmektedir. Nüfus artışının da etkisiyle, ekonomik ve sosyal gereksinimlerin sürekli olarak artması ulaşım ağlarının da genişlemesini beraberinde getirmiştir. Ancak geleneksel ulaşım yaklaşımı bu genişlemeleri gerçekleştirirken sürdürülebilir olmanın gerekliliklerini göz ardı etmektedir. Bu durum ulaşımda aksamalara neden olurken aynı zamanda karbon salınımının da artmasıyla iklim değişikliğini doğrudan tetiklemektedir.

Ulaşım faaliyetlerinin sebep olduğu sera gazı salınımını istatistiksel verilerle de desteklemek mümkündür. Avrupa Birliği ülkelerinde sera gazı emisyonlarının dörtte birine ulaşım faaliyetleri neden olmaktadır. Avrupa Çevre Ajansı'nın yayınladığı rapora göre; 1990 ile 2019 yılları arasında ulaşım kaynaklı sera gazı salınımı %33 oranında artmıştır. Bu oran içerisindeki en büyük pay karayolu taşımacılığına aittir. 2000 ila 2019 yılları arasında yapılan araştırmalarda ise binek otomobil kaynaklı emisyon oranları %5,8, ağır vasıta kaynaklı emisyon oranları ise %5,5 artış göstermiştir (AÇA, 2021). Ulaşımdan kaynaklanan sera gazı salınımları yalnızca yakıt kullanımları ile sınırlı bir etken değildir. Şekil 1'de yol yapım aşamaları yer almaktadır. Bu aşamaların hemen hemen her birinde enerji sarfiyatı ve sera gazı salınımı meydana gelmektedir. Ulaşım ağlarının genişlemesiyle birlikte daha çok yol yapımı, daha çok sera gazı salınımı anlamına gelmekle birlikte bu durum dahi tek başına iklim değişikliğini doğrudan olumsuz etkileyebilecek kapasitededir.



Şekil 1: Yol yapım aşamalarında sera gazı salınımı (Demirtürk,2021)

Ulaşım faaliyetlerinin ekosistem üzerindeki etkisini ortaya koymak üzere bir dizi araştırmalar gerçekleştirilmiştir. 1990 yılında Kenworty ve Newman'ın ulaşımda kullanılan enerji tüketimine dair bir farkındalık yaratmak adına 32 büyük şehir üzerinden yürüttüğü çalışma bu araştırmalara örnek olarak gösterilebilir. Şehirlerin seçiminde ulaşım sektöründe bazı karakteristik özellikler etkili olmuştur. Örneğin; Amsterdam'da bisiklet, Zürih'te hafif raylı sistem, Münih'te yaya yolu düzenlemeleri gibi uygulamalar bu kentlerin araştırma kapsamında öne çıkan özellikleridir. Araştırma sürecinde kentlerin arazi kullanım

yoğunlukları, yenilenebilir enerji teşvikleri, trafik kısıtlama ve düzenlemeleri incelenmiştir. Araştırmanın sonucunda ise toplu taşıma kullanımının artması, bisiklet kullanımının teşviki, yaya ulaşımının düzenlenmesi, yakıt tüketim kriterlerinin konması gibi faktörlerin; hem ulaşımda düzenin tahsisine yardımcı oldukları hem de sera gazı emisyonunda gerileme sağlayarak çevrenin korunmasında önemli rol oynadıkları ortaya konmuştur (Buldurur, 2018). Bu çalışmanın en önemli çıktısı, ulaşımda etkin planlamanın doğru uygulamalarla desteklenmesi durumunda ulaşımda gerçekleşecek iyileştirmelerin iklim değişikliği ile mücadeleye doğrudan katkı sağlayabileceğinin ispatlanmasıdır.

SÜRDÜRÜLEBİLİR ULAŞIM POLİTİKALARI

Krizler mevcut aksaklıkları ortaya koyan sınavlardır. Sorunların doğru teşhis edilip, yeni yaklaşımlarla çözümlenmesi gerekmektedir. Bu doğrultuda 20.yy'ın sonlarında yönetişim, sürdürülebilirlik, kalkınma gibi yeni kavramlar ile desteklenerek yeni yaklaşımlar ulusal ve uluslararası programlarda yer bulmaya başlamıştır. Dünya Çevre ve Kalkınma Komisyonu'nca hazırlanarak Birleşmiş Milletler tarafından yayınlanan 'Ortak Geleceğimiz', bir diğer adıyla Brundlant Raporu'nda ilk kez yer alan 'sürdürülebilir kalkınma kavramı' bu yeni yaklaşımlara önemli bir örnektir. Sürdürülebilir kalkınma 'bugünün gereksinimlerini, gelecek kuşakların da kendi gereksinimlerini karşılayabilme olanağından ödün vermeksizin karşılayan kalkınma' şeklinde tanımlanmaktadır (Gürer ve Köşker, 2021). 21.yy'ın başlarında Birleşmiş Milletler tarafından belirlenen Binyıl Kalkınma Hedeflerinin devamı niteliğinde ve aynı zamanda daha bütüncül politikalarla desteklenen 17 hedef doğrultusunda sürdürülebilir kalkınmanın ilkeleri belirlenmiştir (UNESCO, 2015). Sürdürülebilir kalkınmayı önemli kılan, yalnızca iktisadi bir planlamadan ibaret olmayıp; kaynakların etkin kullanımı ve çevrenin de korunmasıyla daha yaşanılabilir bir dünya hedefi taşımasıdır.

Sürdürülebilirlik, kalkınma ve iklim değişikliği arasında bir köprü görevi gören sürdürülebilir kalkınmanın önemli sacayaklarından biri de ulaşım politikalarının önemidir. Geleneksel ulaşım politikaları, trafik sıkışıklığını önlemek için trafik akış kapasitesini artırmakla yetinen, ulaşım ve altyapı üzerine yoğunlaşan, katılımcılığın sınırlı olduğu, maliyet faydalarını göz ardı eden, kısa ve orta vadeli bir bakış açısına sahipken; sürdürülebilir ulaşım politikaları uygun maliyetli alternatif çözümler arayan, sosyal eşitlik ve çevrenin korunması gibi ilkeleri göz önünde bulunduran, paydaş katılımcılığını önemseyen, disiplinler arası işbirliğine başvuran, kısa ve orta vadeli planları uzun dönemli bir vizyonla belirleyen bütüncül bir yaklaşımdır (Korkmazyürek ve Polat, 2019). Bu farklılıklar aynı zamanda geleneksel ulaşım politikalarının yetersizliğini de tarif etmektedir.

Sürdürülebilir ulaşım politikalarının temelini çekme ve itme politikaları inşa etmektedir. Çekme politikaları, çevre dostu alternatifleri daha cazip hale getirerek ulaşımda tercih edilmelerine olanak sağlayan uygulamalardır. İtme politikaları ise bireysel otomobil kullanımı gibi daha çok karbon salınımına neden olan alternatiflerin caydırıcılığına yönelik düzenlemelerdir. Çekme politikaları toplu taşıma ve motorsuz ulaşım gibi çevresel ve sosyal avantajları olan alternatiflerin yaygınlaştırılmasını sağlar. İtme politikalar ise yol ücretlendirmesi, park yönetimi, trafik yavaşlatma ve vergi düzenlemeleri gibi ekonomik tedbirlerden oluşmaktadır (Cirit, 2014). Burada önemli olan doğru planlamalar yapılarak dengenin gözetilmesidir. Aşırıya kaçan uygulamaların bir çözüm sunmak yerine yeni sorunlar meydana getirmesi kaçınılmaz olacaktır.

Sürdürülebilir ulaşımda önemli aktörlerden bir diğeri çevre dostu enerji alternatifleridir. Fosil yakıt kullanımı ve endüstriyel süreçler zarfında gerçekleşen karbondioksit salınımı %65 gibi kritik bir orana sahiptir. Ulaşım faaliyetlerinin bu oran içindeki payı son derece yüksektir (Demirtürk, 2021). Bu nedenle sürdürülebilir ulaşımın iklim değişikliği ile mücadeleye katkı sunabilmesi adına fosil yakıt kullanımına çeşitli alternatifler geliştirmek zaruridir. Bu bağlamda; hidrojen enerji sistemleri, bor, biyodizel, güneş pilleri ve güneş enerjisi, elektrot-elektrolit sistemleri ile elektrik enerjisi üzerine çalışmalar yürütülmektedir (Aydemir, 2020). Bugünün koşullarında uygulamada en çok karşılaşılan alternatif elektrik enerjisidir. Elektrikli araç sistemleri düşük emisyon oranlarına sahip olmakla birlikte aynı zamanda gürültü gibi çevre kirlilikleri üzerinde de olumlu etkileri olan bir alternatiftir. Teknolojinin de getirileri ile birlikte yeni uygulamalar ortaya konmakta ve gelişmeler sürmektedir. Örneğin Avustralya'da deniz turizmi yıllık 70.000 ton karbondioksit salınımına sebep olmaktadır. Bu miktar hem deniz hem de hava kirliliği üzerinde önemli etkiler yapabilecek bir seviyedir. Bu seviyenin düşürülebilmesi amacıyla güneş enerjisiyle çalışan deniz tekneleri tasarlanmıştır. Uygulamada başarılı sonuçlar veren bu tekneler, hacmi yüksek gemiler üzerinde de güneş enerjisi kullanımına yönelik çalışmalara ilham olmuştur (Tercan, 2021).

Sürdürülebilir ulaşım politikalarının önemli getirilerinden bir diğeri de akıllı ulaşım sistemleridir. Akıllı ulaşım sistemleri, sürdürülebilir ulaşım politikalarının dijital gelişmeler ile desteklenmesini amaçlamaktadır. Trafiğin olağan akışının kontrolü, veri havuzu oluşturulması, toplu ulaşım sistemlerinin iyileştirilmesi gibi zengin bir içeriğe sahiptirler. Akıllı ulaşım sistemleri; yol güvenliğinin sağlanması, hız limitlerinin aşılmaması gibi denetleyici unsurlar barındırmasının yanında toplu taşıma güzergah ve saatlerinin de kullanıcılara ulaştırılabilmesi gibi birçok kazanım sağlamaktadırlar (Buldurur, 2018). Akıllı ulaşım sistemlerinin karar alma süreçlerinde ulaşımın seyrini daha kolay çözümleyebilme ve yeni düzenlemelerin uygulamaya konması noktasında da rolü büyüktür. Böylelikle akıllı ulaşım sistemleri, sürdürülebilir ulaşım politikalarına dijital bir bütünlük sunmaktadır.

SONUÇ

İklim değişikliği ile mücadele tüm insanlığın ortak görevi ve gelecek nesillere borcudur. Dünya üzerinde sınırlı kaynakların sınırsız ihtiyaçlara cevap verebilmesi mümkün değildir. Bu nedenle kaynak kullanımının doğru planlamalar çerçevesinde kalkınmaya hizmet etmesi gerekmektedir. Sürdürülebilir kalkınma bu noktada karşımıza çıkan başat aktördür. İktisadi kalkınma sağlanırken, sosyal ve çevresel faktörlerin de gözetilmesi eşitsizliklerin giderilmesi için son derece önem arz etmektedir. Sanayi devrimiyle birlikte artan üretim iştahı, bilinçsiz tüketim, doğanın tahribatı gibi nedenler ekosistem üzerinde olumsuz etkilerini her geçen gün daha belirgin hissettirmektedir. İnsanlık tarihinin acı tecrübelerinden olan Covid-19 salgın döneminde; sera gazı salınımlarındaki düşüş, çevresel faktörlerdeki çeşitli iyileşmeler iklim değişikliği ile mücadele edebilmek adına halen vaktimiz olduğunu bizlere ispatlamıştır.

Ulaşım faaliyetleri bugünün dünyasında bir yerden bir yere erişimin çok ötesinde anlam ve öneme sahiptir. Ulaşım; lojistik faaliyetleri, hammadde transferleri, seyahatler ve birçok alanda hayatın hemen hemen her anında kaçınılmaz bir ihtiyaçtır. Gerek ulaşım faaliyetlerinin aksamaması, gerekse doğal dengenin daha fazla zarar görmemesi için ulaşım politikalarının yeniden gözden geçirilmesi gerekmektedir. Bu noktada sürdürülebilir ulaşım politikaları çözüm arayışlarında önemli bir rehber niteliğindedir. İnsanları bireysel araç kullanımından ve fosil yakıtlardan uzaklaştırabilmenin en önemli yolu iklim dostu ulaşım alternatiflerini cazip hale getirmektir. Bu doğrultuda yapılacak planlamaların doğru sonuçlar verebilmesi için; disiplinler arası iletişimi güçlü ve katılımcılığın mümkün mertebe yüksek olduğu karar mekanizmaları inşa edilmelidir.

Sürdürülebilir ulaşım politikaları sayesinde karbon salınımını tamamen durdurmak mümkün olmasa da, önemli oranda azaltım sağlayabilmek mümkündür. Çok yönlü ve uygulanabilir projelerin hayata geçmesiyle birlikte bireysel tercihler toplumsal tercihlere dönüşerek güçlü bir mücadele mekanizması haline gelecektir. Sürdürülebilir ulaşım politikaları yalnızca çevre kirliliğinin önlenmesiyle sınırlı değildir. Yaya ulaşımı ve bisiklet kullanımının teşviki insan sağlığını, toplu taşımanın teşviki sosyal iletişimi güçlendirebilecek araçlardır. Bir bütün olarak düşünüldüğünde sürdürülebilir ulaşım politikaları küresel düzeyde; kalkınmanın, ekosistem dengesinin, eşitsizliklerin giderilmesinin ve daha yaşanılabilir bir dünyanın önemli aktörlerinden biri olarak karşımıza çıkmaktadır.

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DEĞİŞEN ENERJİ GÜVENLİĞİ ÇERÇEVESİNDE RUSYA'NIN NÜKLEER ENERJİ HEDEFLERİ: ROSATOM'UN ORTA DOĞU UYGULAMALARI

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ÖZET

Uluslararası sistemde gelişen teknolojiyle birlikte insanlığa karşı tehditlerinde değişime uğradığı görülmüştür. Bu durum uluslararası güvenliğin sağlanmasında önem arz eden enerji güvenliğini de daha görünür hale getirmiştir. Bu çerçevede uluslararası sistemde devletler nükleer enerjiye yönelmişlerdir. Nükleer enerji, küreselleşmenin etkisi ile yaygın hale gelmiş ve devletler açısından önemli bir enerji kaynağı olarak görülmeye başlanmıştır. Nükleer enerjinin, diğer enerji kaynaklarına alternatif olarak görülmesi ve nükleer silah üretimi nedeniyle devletler için önemi giderek artmıştır. Nükleer enerji, sadece atom bombası üretiminde değil özellikle İkinci Dünya Savaşı sonrasında artan petrol fiyatları sonucunda elektrik üretiminde de kullanılmıştır. SSCB'nin yıkılmasının ardından kurulan Rusya'nın SSCB'nin geleneklerini devam ettirdiği görülmüştür. Bu kapsamda, Rusya, teknolojik egemenlik ve düşük karbon enerjisi temelinde çalışmalar gerçekleştirmiştir. Bu çalışmalardan biri de Rosatom adı altında Moskova merkezli devlet şirketinin kurulmasıdır. Rosatom, Rusya'nın tüm nükleer faaliyetlerini yürüten bir kuruluştur. Rosatom, nükleer enerji ile çalışan buz kıran donanmasına sahip tek kuruluş olarak karşımıza çıkmıştır. Rosatom'un nükleer enerji faaliyetleri Rusya'nın küreselleşmenin etkisi ile değişen uluslararası sistemde enerji konusunda süper güç olma yolunda politikalar izlediğini göstermiştir. Rosatom, nükleer enerjinin diğer enerji kaynaklarına dönüştürülmesi ile enerji kaynaklarına daha düşük maliyet ile sahip olunmasını amaçlamıştır. Rosatom, Orta Doğu ülkeleri nükleer enerji alımı ve yatırımları hakkında çok yoğun bir uluslararası nükleer diplomasi girişimi yürütmektedir. Buna örnek olarak, Mısır'ın ilk nükleer güç santral yapımı için Rusya–Mısır arasında nükleer enerji yatırımı mutabakatı imzalanmıştır. Rosatom'un yürüttüğü diğer önemli proje MENA bölgesinde bulunan, Türkiye'deki Akkuyu NGS projesidir. Orta Doğu'da başlatılan nükleer enerji temelli projeler kapsamında petrol tüketiminin azaltılması amaçlanmıştır. Bu durum ile çevre kirliliği azaltılmış ve düşük maliyette enerji üretimi sağlanmıştır. Bu çalışmada, nükleer enerjinin uluslararası arenadaki önemi açıklanırken Rusya'nın nükleer enerji konusunda yapmış olduğu çalışmalara odaklanılmış ve Rosatom'un Orta Doğu uygulamalarının üzerinden bir analiz yapılırken Orta Doğu uygulamalarının amaçları sunulmuştur. Çalışmada, Rosatom'un son dönemdeki yapmış olduğu nükleer enerji faaliyetlerinin verilerinden faydanılmıştır.

Anahtar Kelimeler: Enerji, Nükleer Enerji, Orta Doğu, Rosatom, Rusya.

RUSSIA'S NUCLEAR ENERGY TARGETS IN THE CHANGING ENERGY SECURITY ENVIRONMENT: ROSATOM'S MIDDLE EAST APPLICATIONS

ABSTRACT

It has been observed that threats against humanity have changed with the developing technology in the international system. In the face of this situation, energy security, which has an important place in ensuring international security and in the global system, has gained more importance as a result of these changing threats. In this context, nuclear energy has gained importance for states in the international system. Nuclear energy has become widespread with the influence of globalization and has begun to be seen as an important energy source for states. Nuclear energy has been considered important by states in terms of being seen as an alternative to energy sources and the production of nuclear weapons. Nuclear energy is of great importance as

a result of the changing understanding of security with the changing threats in the international system. Nuclear energy was used not only in the production of atomic bombs but also in the production of electricity, especially as a result of the increasing oil prices after the Second World War. In this context, nuclear energy has been seen as an alternative to traditional energy sources. It has been observed that there has been a race between the Soviet Union (USSR) and the United States of America (USA) in the historical process within the scope of nuclear energy. It has been seen that Russia, which was established after the collapse of the USSR, continued the traditions of the USSR. In this context, Russia has focused on nuclear deterrence in the international arena by improving itself in systematic nuclear weapons. At the same time, Russia has carried out studies on the basis of technological sovereignty and low carbon energy. One of these efforts is the establishment of a Moscow-based state company under the name Rosatom. Rosatom is an organization that carries out all nuclear activities of Russia. Rosatom emerged as the only organization with a nuclear-powered icebreaker navy. Rosatom's nuclear energy activities have shown that Russia is pursuing policies to become a superpower in energy in the international system changing with the impact of globalization. Rosatom aims to obtain energy resources at lower costs by converting nuclear energy into other energy sources. Rosatom carries out a very intense international nuclear diplomacy initiative regarding nuclear energy purchases and investments in Middle Eastern countries. As an example, a nuclear energy investment agreement was signed between Russia and Egypt for the construction of Egypt's first nuclear power plant. Another important project carried out by Rosatom is the Akkuyu NPP project in Turkey, located in the MENA region. It is aimed to reduce oil consumption within the scope of nuclear energy-based projects initiated in the Middle East. With this situation, environmental pollution has been reduced and low-cost energy production has been achieved. In this study, while explaining the importance of nuclear energy in the international arena, Russia's studies on nuclear energy are focused on, and while an analysis is made on Rosatom's Middle East applications, the aims of the Middle East applications are presented. In the study, data from Rosatom's recent nuclear energy activities were used.

Keywords: Energy, Nuclear Energy, Middle East, Rosatom, Russia.

GİRİŞ

Uluslararası sistemde en önemli konulardan bir tanesi enerji güvenliğidir. Enerji güvenliği, enerji kaynağının üretici ülkeden, belirli istikametlerde problemsiz, güvenli, sürdürülebilir bir şekilde tedarikçi ülkeye ulaştırılması olarak tanımlanabilir. Küreselleşmenin giderek artan etkisi sonucunda enerji güvenliği anlayışı da değişime uğramıştır. Enerji güvenliğinde en önemli mesele enerji güvenliği sorunlarında zaman içerisinde artış yaşanmasıdır. Enerji güvenliği sorunları, uluslararası sistemde var olan tehditler sonucunda yaşanmaktadır. Küreselleşme ile tehditlerin farklılaşması enerji güvenliğinin de değişmesi anlamına gelmektedir. Önemli enerji krizlerinden biri olan 1973 Petrol Krizi ile petrol fiyatlarının arttırılarak enerji kaynaklarının bir silah olarak kullanılmasının ardından petrole duyulan ihtiyacı azaltmak amacı doğrultusunda ulus-devletler nükleer enerjiye geçişi hızlandırmışlardır.

Nükleer enerji, en sık kullanılan uranyum maddesinin atom çekirdeğinin parçalanması ile oluşturulan ve reaksiyonlarla farklı enerji türlerine dönüştürülen bir enerji türüdür. Uluslararası sistemde Nükleer enerjiyi destekleyen ya da radyasyon tehdidi olarak gören nükleer enerjiye karşı olan taraflar mevcuttur. Bu kapsamda karşı düşünceler mevcut olsa da nükleer enerji üretimi maliyetlerinin petrol üretim maliyetlerinden daha düşük olması nedeni ile ulus-devletler tarafından önemli bir enerji olarak görülmekte ve tercih edilmektedir. Ulus-devletler nükleer enerji konusunda önemli projeler geliştirmekte ve bunları uygulamaya koymaktadırlar. Bu konuda çalışmanın merkezinde yer alan Rusya, nükleer enerji faaliyetlerini yürütecek bir devlet şirketi kurmuştur. Rusya Devlet Atom Enerji Kurumu (Rosatom) adıyla kurumuş olan bu şirket Rusya'nın nükleer enerji konusunda gelişmesi adına birçok projeyi geliştirmiş ve uygulamaya geçirmiştir.

Rosatom, nükleer güç santralleri inşasında birçok ülkede çalışmalar yürütmüş ve yürütmeye de devam etmektedir. Rosatom'un özellikle petrol zengini olan Orta Doğu'da projeler planladığı görülmektedir. Bunun sebebi Orta Doğu'nun petrolü en çok kullanan ülkelerden oluşmasıdır. Bu bağlamda, Orta Doğu'da enerji çeşitliliği ile petrol kullanımının azaltılması amaçlanmıştır. Rosatom nükleer enerji uygulamaları ile asıl amacın Rusya'nın Sovyetler Birliği'nden miras kalan yayılmacı politikasını devam ettirmek olduğu söylenebilir. Yine Rusya, Orta Doğu ve Afrika gibi enerji kaynakları bakımından zengin bölgelerle iyi ilişkiler kurarak hegemon güç oluşturmaya çalışmıştır. Bu kapsamda, Rosatom aracılığıyla Rusya yeni stratejiler geliştirmeye devam etmiştir. Rosatom'un uluslararası sistemde planladığı çalışmalar, çalışma bölgeleri yeni stratejiler geliştirmesi sebebi ile önemli bir konudur.

Bu çerçevede çalışmada,

- Nükleer enerji kullanımı dezavantajlarına rağmen artış gösterecek mi?
- Rosatom çerçevesinde Rusya'nın enerji kapsamında yeni stratejileri nelerdir?
- Rosatom, nükleer enerjide istediği hedeflerine ulaşabilecek mi?

sorularına cevap aranmıştır.

Çalışmanın hipotezleri

- Nükleer enerji kullanımı dezavantajlarına rağmen önümüzdeki 20-30 yıl içerisinde yükselişe geçerek nükleer enerjiye duyulan ihtiyaç artacaktır.
- Rosatom çerçevesinde Rusya nükleer enerji kapsamında ulus-devletlerin hayır diyemeyeceği projeler hazırlamakta ve bunları uygulamaya geçirmektedir.
- Rosatom, bu şekilde projelerini gerçekleştirmeye devam ederse Rusya nükleer enerji hedeflerine ulaşacaktır.

Bu çalışmanın ilk bölümünde günümüzde sıkça duyduğumuz nükleer enerjinin tanımına, ikinci bölümünde Rusya'nın nükleer enerji faaliyetlerine, üçüncü bölümde Rusya merkezli bir kuruluş olan Rosatom'un işlevlerinin neler olduğuna, dördüncü bölümde Rosatom'un Orta Doğu projelerinden ve uygulamalarından örnekler verilerek enerji güvenliğine olan katkısı tartışılarak ABD, Orta Doğu ve diğer ulus-devletlerin Rosatom'a bakış açısının nasıl olduğu açıklanarak sonuca bağlanmıştır.

MATERYAL VE METOD

Bu çalışma nitel araştırma yöntemleri kullanılarak hazırlanmıştır. Araştırmalar yapılırken yerli ve yabancı literatürden yararlanılmıştır. Çalışma için gerekli olan veriler için farklı dillerdeki kaynaklardan da yararlanılmıştır. Yine çalışmanın ortaya çıkartılmasında enstitülerin güncel verileri kullanılmış ve güncel verilerin değerlendirilmesinden, küresel enerji raporlarından, durum çalışması yöntemlerinden yararlanılarak neden sonuç ilişkisi çerçevesinde sonuca bağlanmıştır. Yöntem bakımından ise çalışmada önce ilgili kavramlar ele alınmış olup sırasıyla Rusya'nın nükleer enerji faaliyetleri, Rosatom'un hedefleri çerçevesinde Orta Doğu'da uyguladığı projelere ve bunun uluslararası sisteme yansımalarına yer verilmiştir.

BULGULAR VE TARTIŞMALAR

Nükleer Enerji Nedir?

Enerji kaynakları, geçmişten günümüze kadar önemli bir değişime uğramıştır. Küreselleşmenin etkisi ile enerji kaynakları giderek çeşitlenmiştir. Geçmişten bugüne enerji kaynaklarını inceleyecek olursak enerji, ulus-devletlerin ısınmak, ulaşım vb. konularda ihtiyaç duyduğu kaynaklar olarak tanımlanmıştır. Enerji; yenilenebilir enerji ve yenilenemez enerji olarak iki grupta sınıflandırılır. Yenilenebilir enerji kavramı, enerji üretiminin doğal yollardan sağlandığı ve kendini kısa sürede yenileyebilen enerji kaynakları için kullanılmıştır. Yenilenebilen enerji kaynaklarına *güneş enerjisi, rüzgâr enerjisi, hidroelektrik enerjisi*, biyokütle enerjisi örnek verilebilir. Yenilenemeyen enerji kavramı, organik kaynakların zamanla fosilleşerek oluşturduğu ve kullanıldıkça tükenen kaynaklar olarak tanımlanmıştır (TUİÇ Akademi, 2014). Bu kapsamda uluslararası sistemde öneme sahip olan enerji kaynakları yenilenebilir ve yenilenemez enerji kaynakları olarak sınıflandırılmıştır.

Yenilenemeyen enerji kaynakları, birincil enerji kaynakları olarak da adlandırılmıştır. Birincil kaynaklara; kömür, petrol vb. kaynaklar örnek verilebilir. Birincil enerji kaynaklarından olan kömür, petrol, doğalgaza duyulan ihtiyaç küreselleşmenin etkisi sonucunda artan enerji tüketimi ile doğru orantılı olarak her geçen gün artmaktadır. Enerji kaynaklarına duyulan ihtiyacın artması enerji kaynakları bakımından zengin bölgelerin prestijini ve önemini de arttırmıştır. Enerji kaynakları bakımından zengin olan bölgeleri elinde bulunduran ülkeler güç dengesine sahip olur anlayışı hâkim olmuştur. Tarihsel süreç incelendiğinde ulus-devletler arasında enerji temelli birçok çatışma yaşanmıştır. Yaşanılan çatışmalar uluslararası arenada güvenliği olumsuz yönde

etkilemiştir (TUİÇ Akademi, 2014). Enerji kaynakları, uluslararası sistemde bir güç olarak görülmüştür. Bu bağlamda, enerji kaynaklarını elinde bulunduran ulus-devletler güç dengesini de elinde bulundurmaktadır.

Bunun yanında 1973 Petrol Krizi sonrasında petrole duyulan ihtiyacın azaltılması amacı ile atom çekirdeğinin parçalanması ile elde edilen bir enerji olan nükleer enerji üretimi yapan nükleer güç santrallerinin kurulumunu hızlandırılmıştır. Atom çekirdeğinden elde edilen nükleer enerji; savunma sanayi, tıp, endüstri de kullanılmaktadır ve reaksiyonlar sonucunda elektrik enerjisine dönüştürülmektedir. Nükleer enerji üretiminde en sık atomlarına kolay ayrılan uranyum maddesi kullanılmaktadır. Bu kapsamda, uranyum bakımından zengin olan bölgeler nükleer enerji üreten devletler için önemli hale gelmiştir (Engin, 2013). Bu nedenle nükleer enerji, yaşanılan enerji temelli küresel krizler sonucunda enerji kaynaklarının bir silah olarak kullanılması bazı ulus-devletler tarafından önlenmek istemiştir.

Rusya'nın Nükleer Enerji Uygulamaları

Rusya'da nükleer enerji geçmişi, Sovyetler Birliği (SSCB) dönemine dayanmaktadır. SSCB'nin nükleer enerji teknolojisine önem vermesi vizyonunu geliştirmesini sağlamıştır. SSCB'de diğer ulus-devletlerde olduğu gibi nükleer enerjiyi, askeri teknolojisini geliştirmek amacı ile önemli görmüştür. Stalin döneminde başlayan nükleer enerji yolundaki gelişmeler Stalin yönetiminden sonrada hızla devam etmiştir. Paul Josephson, "Kırmızı Atom" adlı eserinde SSCB'nin nükleer enerjiyi Sosyalist bir vizyon oluşturmak amacı ile önemsediğini ve bu durumun bir ütopya olduğuna yer vermiştir. Yine Krusçev yönetimi döneminde SSCB, Amerika Birleşik Devletleri (ABD) ile bilimdeki yarışını devam ettirmiştir. Nükleer enerji gelişimi de bunu içerisinde yer almaktadır. Bu dönemde materyalizm çerçevesinde oluşturulan yeni politikalar benimsenmiş ve bu alanda bilim insanları yetiştirilmiştir (Josephson, 1999, s. 3). Bu kapsamda, SSCB'nin, vizyonunu değiştirmek amacı doğrultusunda yeni bakış açıları ile politikalar oluşturduğu görülmüştür. SSCB, güç dengesini elinde bulundurmak amacıyla enerji kaynakları üzerinde söz sahibi olmayı amaçlamıştır.

SSCB bilim insanlarından Igor Kurchatov, atom bombasının mimarı lakabı ile de bilinmektedir. Kurchatov, SSCB'nin barışçıl olarak nitelendirilen nükleer programında yer alarak nükleer güç santrallerini denetlemiştir. Materyalist bir bakış açısıyla oluşturulan politikalar kapsamında SSCB otoritesi altında olan bölgelerde nükleer güç santralleri kurulması öngörülmüştür (Josephson, 1999, s. 4). SSCB dağılmadan önceki bu politikalar çerçevesinde SSCB'nin yayılmacı politikasını enerji temelli ve materyalist bir bakış açısı ile bilim adı altında yürüttüğü görülmüştür.

Rusya, SSCB'den miras kalan nükleer enerji üretiminde uluslararası sistemde önde gelen ulus-devletlerdendir. Rusya, geçmişten bugüne enerji kaynaklarına çok fazla önem vermiştir. Rusya'nın enerji kaynaklarına önem verme sebebi arasında güç dengesini elinde bulundurarak uluslararası sistemde süper güç olma isteği mevcuttur (Sputniknews.com, 2023). Bu kapsamda Rusya, enerji kaynakları konusunda önemli projeler uygulamıştır.

Rusya, nükleer güç santrallerinin inşası konusunda çalışmalar yapmış olsa da bu santrallerde çalıştırılacak kadroları yetiştirmek amacı doğrultusunda nükleer güç santrallerinin kurulduğu ulus-devletlerden öğrencilerin Rusya'da nükleer enerji mühendisliği alanında eğitim alması için gerekli girişimler yapmıştır. Buna örnek vermek gerekirse Türkiye'den Rusya'ya gönderilen öğrencilerden 2018'de 35'i, 2019'da 53'ü, 2020'de 55'i mezun olarak Türkiye'ye dönüş yapmış ve Türkiye'de bulunan Akkuyu Nükleer Güç Santrali (NGS)'nde çalışmaya başlamıştır (Sputniknews.com, 2023). Bu bağlamda Rusya'nın nükleer enerji konusunda bilime de önem verdiği görülmüştür. Nükleer güç santralleri ilgili bölgelerde inşa edilirken aynı zamanda buralarda görev alacak bilim insanları da yetiştirilmiştir.

Rusya'nın nükleer enerji konusunda yaptığı faaliyetlerden bir diğeri de Rusya için büyük öneme sahip olan ve nükleer enerji konusunda büyük projeler gerçekleştiren Rusya Devlet Atom Enerjisi Kurumu (Rosatom)'nu kurmasıdır (Thompson, 2018). Rosatom'un kurulması ile Rusya'nın tüm nükleer faaliyetleri bu şirket tarafından yürütülmüş ve nükleer enerji politikaları direkt ulus-devlet üzerinden değil devlete bağlı olan şirket tarafından uygulanmıştır. Rusya'nın bu şekilde önemli bir adım atmış olması diğer ulus-devletler açısından da önemli bir gelişme olarak görülmüştür.

Rosatom ve Orta Doğu Uygulamaları

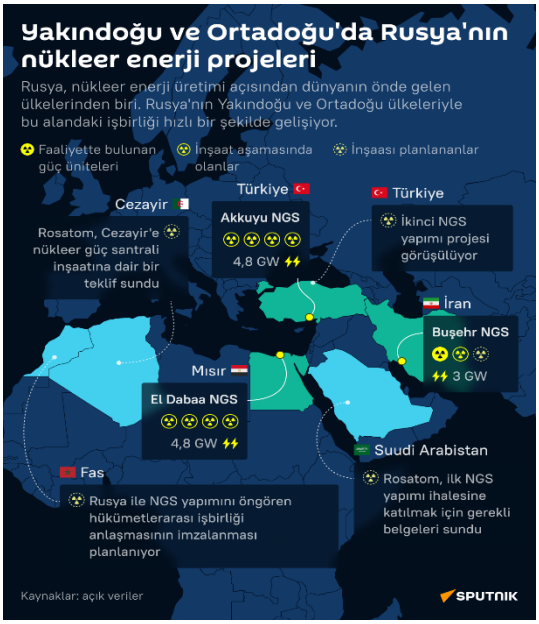
Rosatom, Rusya'nın tüm nükleer enerji faaliyetlerini yürüten bir devlet şirketidir. Yine Rosatom, nükleer enerji ile çalışan buz kıran donanmasına sahip tek kuruluş olarak karşımıza çıkmaktadır. Rosatom'un nükleer enerji

faaliyetleri Rusya'nın küreselleşmenin etkisi ile değişen uluslararası sistemde enerji konusunda süper güç olma yolunda politikalar izlediğini göstermiştir. Rosatom, nükleer enerjinin diğer enerji kaynaklarına dönüştürülmesi ile enerji kaynaklarına daha düşük maliyet ile sahip olunmasını amaçlamıştır (Rosatom, 2023). Bu kapsamda Rosatom'un, Rusya'nın süper güç olma yolunda izlediği stratejilerden biri olduğu yorumu yapılabilir. Pazar arayışında olan Rosatom, Orta Doğu ülkeleri nükleer enerji alımı ve yatırımları hakkında çok yoğun bir uluslararası nükleer diplomasi girişimi yürütmektedir

Rosatom Orta Doğu'da nükleer enerji kaynakları ile ilgili projeler geliştirerek petrole duyulan ihtiyacı azaltmak istemiştir. Bu çerçevede, hem daha düşük maliyette enerji elde edilecek hem de petrol çıkarılırken oluşan çevre kirliliği ortadan kalkmış olacaktır. Rusya'nın nükleer enerji üretimi çerçevesinde Orta Doğu ülkeleri ile olan ilişkileri gelişmiştir. Rosatom faaliyetleri ile Rusya, nükleer enerji üretiminde, uluslararası sistemin önde gelen ülkelerinden olarak enerji kaynakları üzerinde söz sahibi olmayı amaçlamıştır (Sputniknews.com, 2023). Bu çerçevede Rusya, nükleer enerji faaliyetlerini kullanarak ulus-devletler üzerinde hegemonist bir politika izlediği görülmüştür.

Rosatom'un projeleri kapsamında Mısır'ın ilk nükleer güç santral yapımı için Rusya–Mısır arasında nükleer enerji yatırımı mutabakatı imzalanmıştır. Mısır'ın ilk nükleer santrali El-Dabaa'nın inşası ile Mısır'ın yeni bir teknoloji, sanayi ve eğitim geliştirme düzeyine ulaşmasını sağlayacağı açıklamalarda bulunulmuştur. Rusya-Mısır ilişkilerine bakıldığında nükleer santral, Asvan Barajı'ndan bu yana Rus-Mısır işbirliğinin en büyük projesi olarak gösterilebilir (Santiye.com, 2022). Bu bağlamda, nükleer enerji antlaşmaları üzerinden iki devlet arasında ilişkiler geliştirilmeye çalışılmıştır.

Rosatom'un yürüttüğü diğer önemli proje ise MENA bölgesinde bulunan, Türkiye'deki Akkuyu NGS projesidir. Enerji kaynakları bakımdan dışa bağımlı olan Türkiye için inşa edilen bir nükleer santral enerji kaynaklarında dışa olan bağımlılığını azaltmak demektir. Bu bağlamda, nükleer santralin inşası Türkiye açısından büyük öneme sahiptir. Rosatom'un Orta Doğu'daki bir başka faaliyeti de İran'da Buşehr nükleer santralinin kurulması olmuştur. Rosatom, Mısır, Türkiye, İran'da olduğu gibi Suudi Arabistan'da da nükleer enerji santrali inşası için çalışmalarda bulunmuştur (Caferider.com, 2013).



Figür 1. Rosatom'un Orta Doğu Uygulamaları (Sputniknews.com, 2023).

Haritada Rosatom'un Orta Doğu projeleri gösterilmiştir. Aynı zamanda Rosatom'un Orta Doğu uygulamalarının yanında Yakın Doğu, Afrika gibi bölgelerde de proje uygulama planları yapılmıştır. Bu uygulamaların bazıları şu şekilde sıralanabilir:

- Yakın Doğu; Cezayir, Fas
- Afrika

- Macaristan; Paks 2 NGS
- Belarus NGS
- Xudabao NGS
- Bangladeş
- Rooper NGS
- Yakutistan
- Çukotka; altın yatağı için enerji kaynağı projesi (Sputniknews.com, 2023).

Bu bağlamda, Rosatom'un nükleer güç santrali inşası için proje planları yapmış olduğu bölgeler enerji kaynakları ve yeraltı kaynakları bakımından zengin bölgelerdir. Gerçekleştirmiş olduğu faaliyetlerle Rosatom, küreselleşmenin etkisi ile değişen uluslararası sistemde her ulus-devletin kendi enerjisini üreterek enerji güvenliği sorunlarının yaşanmasını engellemeyi amaçladığını göstermiştir.

Orta Doğu Ülkeleri ve Diğer Ulus-Devletlerin Rosatom'a Bakış Açısı

Küreselleşmenin etkisi ile güvenlik alanlarının giderek genişlemesi, tehditlerin artmasına neden olmuştur. Güvenlik konusunda en önemli parametre tehdit kavramıdır. Tehdit; devletin, insanın varlığına ya da değerlerine zarar verme riskine verilen isim olarak tanımlanmıştır. Tehditler ulusal ve uluslararası güvenliği de etkilemiştir. Enerjinin de bu tehditlerle karşı karşıya kaldığı görülmüştür. Bu durumda da Enerji Güvenliği (Energy Security) kavramı ortaya çıkmaktadır. Enerji güvenliği, enerji kaynağının üretici ülkeden, belirli istikametlerde problemsiz, güvenli, sürdürülebilir bir şekilde ithalatçı ülkeye ulaştırılması şeklinde tanımlanabilir. Enerjinin, enerji üreticisi ülkelerden güvenli bir şekilde enerji ihtiyacı olan enerji ihtiyacı olan ülkelere ulaşması elzem bir konudur. Enerji güvenliği, uluslararası güvensizliğin bir sebebi olarak da değerlendirilebilir. Küreselleşme ile enerji kaynaklarına duyulan ihtiyacın artması, enerji kaynakları bakımından zengin bölgelere kamuoyunun ilgisinin artmasına neden olmuştur (TUİÇ Akademi, 2014). Dünya kamuoyunun ilgisinin arttığı enerji kaynakları bakımından zengin bölgelerde yaşanılan bölgesel krizler büyüyerek küresel krize dönüşmüş ve enerji güvenliği konusunda önemli sorunlara neden olmuştur.

Orta Doğu ülkeleri petrol bakımından zengin bölgeler olduğu için uluslararası sistemde kamuoyunun her dönem ilgi odağı olmuştur. Geçmişten bugüne Orta Doğu incelenecek olursa ABD gibi büyük güçlerin bu bölgeye büyük ilgisi olduğu görülmüştür. Bu çerçevede, Orta Doğu ile başka ulus-devletlerin iyi ikili ilişkiler kurması diğer ulus-devletleri rahatsız etmiştir. Rosatom'un da Orta Doğu uygulamaları bu sebeple diğer ulus-devletler tarafından tepki görmüştür (Sudagezer, 2020). Bu bağlamda, ulus-devletler Rusya'nın bölgedeki nükleer enerji girişimlerini bir tehdit olarak görmüştür.

Rusya Rosatom aracılığı ile birçok nükleer güç santrali projesini gerçekleştirmiştir. Rosatom'a ulus-devletlerin nükleer enerji temelli projelerine sıcak bakmama sebepleri olarak Çernobil ve Fukuşima Daiichi nükleer santral kazalarının yaşanması sonucunda ortaya çıkan sorunlar ve insanlar üzerindeki olumsuz etkisi gösterilebilir. Bu bağlamda nükleer enerji konusunda ulus-devletler içerisinde nükleer enerji karşıtı görüşlerin olduğu söylenilebilir (Ekşi, 2013, s. 87). Bu çerçevede nükleer güç santrallerinin olası bir kazada nükleer güç santrali çevresinde yaşayan toplumlara zarar vereceği ve sorunlara neden olacağı endişesi taşınmaktadır.

Orta Doğu, Yakın Doğu, Afrika gibi birçok bölgede uygulamalar gerçekleştiren Rosatom, projeleri için seçtiği bölgeler nedeniyle bu alanda faaliyet yürüten diğer ulus-devletler ile de yarış halindedir. Ulus-devletler için enerji kaynakları büyük bir öneme sahiptir (Sudagezer, 2020). Bu bağlamda, Rosatom'un uygulamaları enerjide rekabet içinde oldukları diğer ulus-devletleri rahatsız etmektedir.

Rosatom uygulamalarından rahatsız olan devletlerden olan Kanada, Fransa, Japonya, Birleşik Krallık ve ABD Japonya'nın Sapporo kentinde düzenlenen G7 Nükleer Enerji Forumu'nda nükleer sektörde Rusya'ya karşı koyma konusunda anlaşmaya varmıştır. Nükleer enerji çerçevesinde birçok bölgede projelere imza atan

Rosatom'un kapatılması gerektiği gündeme getirilmiştir. ABD ve Rosatom arasında yaşanan Zaporijya NGS sorunu[1], ABD-Rusya arasında yaşanan nükleer enerji rekabetinin en önemli örneklerinden biridir.

Orta Doğu ülkelerinin Rosatom uygulamalarını kabul ettikleri görülmektedir. Bu duruma en iyi örnek ülke Suudi Arabistan'dır. Suudi Arabistan ulusal nükleer güç teknolojisi projeleri talepleri hakkında kaygı duymuştur. ABD'nin önceki Başkanı Donald Trump, Suudi Arabistan'a Amerikan nükleer enerji teknolojileri transferi çalışmalarına nispeten olumlu bakmıştır. Trump, Suudi Arabistan Krallığı yönetimi ile yakın ilişki içinde bulunmuştur. Trump, ekonomik yönden darboğaz yaşayan ve mali sorunlar içine düşen Amerikan nükleer enerji sektörünün canlandırılması taahhütlerini yerine getirmeye çalışmıştır. Suudi Arabistan nükleer güç programı üzerinde Amerika'nın etkinliğinin artması kötü bir seçenek olarak kabul etmiştir. Suudi Arabistan'ın nükleer enerji projeleri programı, diğer küresel nükleer güç tedarikçisi ülkelerin de ilgisini çekmiştir. Rusya'ya ait bir nükleer enerji şirketi olan Rosatom'da, Orta Doğu ülkeleri ile nükleer enerji ihaleleri ve yatırımları hakkında çok yoğun bir uluslararası nükleer diplomasi girişimi yürütmüştür. (Taner, 2020). Bu bağlamda, Suudi Arabistan'ın Rosatom'a güven duyması sonucunda nükleer enerji santral projelerini kabul ettiği görülmüştür. Suudi Arabistan'ın kararlarındaki değişim nükleer enerji üretiminde maliyetin az olması olarak gösterilmiştir.

SONUÇ VE ÖNERİLER

Enerji güvenliği, çatışma ortamının hâkim olduğu uluslararası sistem için önemli konulardan biridir. Enerji kaynaklarını elinde bulunduran ülkeler güç dengesini de elinde bulundurmuştur. Bu bağlamda, enerji kaynakları bakımından zengin Avrasya ve Orta Doğu'yu elinde bulunduran ülke dünyada önemli bir yere sahip olacaktır. Uluslararası sistemde enerji kaynakları bakımından zengin bölgeleri kendi otoritesi altında tutmak isteyen ülkeler çeşitli araçlar kullanarak bu hedeflerine ulaşmak istemişlerdir. Bu şekilde davranışlar sergileyen ülkelerden biri ABD iken diğeri de Rusya'dır. ABD ve Rusya arasında Soğuk Savaş sonrasında başlayan güç çatışmaları ve rekabet küresel krizlere neden olmuştur. Güç savaşı olan bu iki ülkenin sert güce başvurmaları sonucunda enerji güvenliği sorunları yaşanırken aynı zamanda uluslararası arena da güvenliksiz bir ortama dönüşmüştür.

Araştırmalar yapılırken, enerji güvenliğinin uluslararası sistemi oldukça fazla etkilediği, bölgesel krizlerin büyüyerek domino etkisi oluşturması sonucunda küresel krizlere dönüştüğü ve ekonomik anlamda ulus-devletleri olumsuz etkilediği görülmüştür. Yaşanılan küresel krizler sonucunda Batı ülkelerinin yenilenebilir enerji kaynaklarına geçişi hızlandırılmıştır. Bu bağlamda yapılan çalışmalar ile küresel ısınmaya karşı da tedbirler alınmış olacaktır. Diğer taraftan enerji kaynaklarında yaşanan sorun nedeni ile enerji fiyatlarındaki artışın devam edeceği tahmin edilmektedir. Bu durumunda genelde devletleri özelde ise insanların yaşamlarını doğrudan etkilemesi beklenmektedir.

Küreselleşmenin etkisi her geçen gün arttıkça değişen uluslararası sistemde ülkelerin güç savaşı stratejileri de değişime uğramıştır. Güç stratejilerinin değişiminde küresel krizlerin etkisi de büyük olmuştur. 1973 Petrol krizi ile petrol fiyatlarında görülen artış enerji güvenliği sorunlarına neden olmuştur. Buna benzer bir başka örnek ise 2022'de başlayan ve hala devam eden Rusya-Ukrayna savaşıdır. Rusya-Ukrayna savaşının yaşanması sonucunda AB ülkeleri, Rusya'ya olan enerji bağımlılığını bitirmek amacı ile farklı alternatif enerji arayışına başlamışlardır. İki ülke arasında yaşanılan çatışma ülkeler arasında barışı sağlayan karşılıklı bağımlılığı bitirirken güvenliksiz bir ortamı beraberinde getirmiştir. Bu bağlamda, alternatif enerji kaynağı olan nükleer enerjiyi bir stratejik araç olarak gören Rosatom'un projeleri büyük önem kazanmıştır.

Rosatom, Orta Doğu'daki projeleri ile nükleer santraller inşa ederek petrole duyulan ihtiyacın azaltılmasını amaçlamıştır. Bu çerçevede, karbon emisyonunun azaltılması amaçlanmıştır. Orta Doğu ülkelerinin ekonomik gelirlerinin büyük kısmını oluşturan petrolün Orta Doğu'da kullanımının azaltması tepkilere neden olsa da nükleer enerji üretimin daha az maliyetle ve çevre kirliliğine neden olmadan petrole göre daha kolay üretildiği göz önünde bulundurulmalıdır. Uluslararası sistemde küreselleşmenin etkisi ile değişen enerji güvenliğinde ulus-devletler, enerji kaynakları bakımından zengin devletlere bağımlılığını azaltmak için nükleer enerji ve

[1] Zaporijya NGS sorunu, ABD ve Rosatom'un arasında yaşanan bir sorundur. Zaporijya bölgesinin referandum sonrası Rus topraklarına katılmasıyla Rusya'nın mülkü olmuştur. Fakat ABD, Avrupa'nın en büyük nükleer santrali olan Zaporijya Nükleer Santrali'nin ABD'ye ait olduğunu savunmuştur (Rosatom, 2023). Bu çerçevede ABD'nin Rosatom üzerinde Rusya ile bir rekabet halinde olduğu söylenebilir.

yenilenebilir enerji kaynaklarına geçişi hızlandırmıştır. Bu bağlamda, önümüzdeki dönemde petrole duyulan ihtiyaç azalırken, nükleer enerjiye duyulan ihtiyacın artacağı yorumu yapılabilir.

Nükleer enerjiye ihtiyacın artması ve petrole duyulan ihtiyacın azalması sonucunda petrolden ekonomik gelir sağlayan ulus-devletlerin petrol satışlarını oranında büyük bir düşüş olacağı öngörülmektedir. Bu bağlamda, nükleer enerji santrallerinin arttırılması ve yenilenebilir enerji kaynaklarına geçiş yapılması uluslararası sistemde yer alan aktörler için önemli avantajlar sağlayacaktır. Rosatom'un bu kapsamda geleceğe yönelik yatırım yaptığı söylenebilir. Rusya'nın Rosatom uygulamaları çerçevesinde, stratejik öneme sahip ve yeraltı kaynakları bakımından zengin bölgelere doğru bir dış politika izlediği görülmektedir.

Nükleer enerji kullanımı dezavantajlarına rağmen artış gösterecek mi?	Nükleer enerji küreselleşmenin etkisiyle enerji güvenliği sorunlarının da değişmesi sonucunda ilgi duyulan bir enerji türü haline gelmiştir. Rosatom'un, kazancının arttığı da göz önünde bulundurulduğunda nükleer enerji kullanımının artacağı söylenebilir.
Rosatom çerçevesinde Rusya'nın enerji kapsamında yeni stratejileri nelerdir?	Rosatom faaliyetleri kapsamında Rusya, güç savaşları stratejisini geliştirmiştir. Rusya, vizyon değişikliği ile diğer ulus-devletlerle iyi ilişkiler kurarken enerji konusunda otorite sahibi olmayı planlamaktadır.
Rosatom, nükleer enerji çerçevesinde amacına ulaşabilecek mi?	Orta Doğu ülkelerinin nükleer enerji konusunda ABD'ye değil Rosatom'a güveniyor oluşu Rosatom'un gelecekte nükleer enerji hedeflerine ulaşabileceğini bize göstermektedir.

Son tahlilde çalışmanın sonuçları göz önüne alındığında enerjiye olan ihtiyacın hem küreselleşmenin hem de gelişen teknolojilerin etkisiyle giderek artış göstereceği bir gerçektir. Bu nedenle özellikle enerjiye bağımlı ulus-devletlerin yenilenebilir enerji kaynaklarına yönelmesi bir gerekliliktir. Nükleer enerjide bunların en başında gelmektedir. Gerek küresel aktörler olsun gerekse küresel aktör olma potansiyelindeki diğer ulus-devletlerin nükleer enerji santralleri kurarak enerji ihtiyaçlarını sağlama yönündeki faaliyetlerin devam edeceği değerlendirilmektedir. Ayrıca bu alanda öne geçen ülkelerin (Rosatom örneğinde Rusya'nın olduğu gibi) bir sonraki adımının da nükleer enerjiyi bir araç olarak kullanarak diğer ülkeler üzerinde otoriter olma ve nüfuz elde etme niyetleri olduğu ve bunu bir güç olarak kullandığı görülmektedir.

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FLEXIBLE CONNECTION OF DISTRIBUTED ENERGY RESOURCES TO THE GRID

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ABSTRACT

In many electricity distribution systems around the world, the penetration of Distributed Energy Resources at distribution levels is increasing due to the negative impact of traditional fossil fuel energy sources on the climate. This penetration is causing the traditional electricity distribution system to change rapidly. With this change, the way new smart technologies interact with the energy system is also changing. However, while a higher percentage of generation from traditional Distributed Energy Resources (DERs) is promising in terms of decarbonization, it will create problems for distribution system operators and asset owners (producers and consumers) in the long run. In this paper, we propose a new connection type, flexible connection concept, for electricity distribution grids where the number of distributed energy resources and power electronic devices is increasing. The flexible connection method aims to increase the hosting capacity of distributed generation resources, improve the power quality parameters of the grid, ensure energy supply-demand balance, ensure system reliability, and prevent negative market pricing and instability. Firstly, the definitions of the concept of flexibility in the electricity distribution system, flexible connection in the literature, why this concept is needed, and flexible generation, storage and consumption resources, which are flexible energy resource types, are examined. In the next section, the increasing need for flexible resources in electricity distribution systems, different flexibility mechanisms, flexible connection applications in the world are researched and sample applications are included. In addition, flexible connection and flexible curtailment methods, which are widely preferred and currently being implemented in the UK, are examined. In the last section, the benefits of integrating distributed energy resources into the system with flexible connection and the issues that need to be improved in practice are analysed. As a result of the study, it is concluded that flexibility will provide a significant increase in the integration of distributed generation resources, provide alternative connection options for generation plants that want to connect, contribute positively to the sustainability of the system when integrated both on the electricity distribution system side and on the user (producer or consumer) side, increase system resilience especially at times of peak energy consumption, and reduce operating and investment costs. Energy storage facilities appear to be an important factor in resilience. However, there are many issues that need to be developed and researched, such as flexible assets, flexibility parameters, the effects on the transmission side and the energy market etc.

Keywords: Distributed energy resources, Electric power systems, Flexible connection, Flexible concept, Flexible resources, Hosting capacity.

Introduction

Energy production technique is an important issue in terms of greenhouse gas emissions (Ritchie H, 2022). The energy sector is the sector most responsible for greenhouse gas emissions with a share of some 75%. Energy-related CO2 emissions are projected to increase from 33 GHG in 2015 to 35 GHG in 2050 under current and planned policies (Gielen et al., 2019), and the share of renewable energy sources needs to increase from 25% to 85% by 2050 to meet the targets of the Paris summit agreement (Essayeh & Morstyn, 2023).

While renewable energy has the potential to meet the entire primary energy demand, it is not without its challenges. Power system flexibility is one of these challenges.

The lack of flexibility of modern power grids can be demonstrated by various factors such as insufficient supply to meet demand, especially during peak hours, significant reductions in renewable energy, balance of area violations, instability, unfavorable market pricing and others(Hussain et al., 2023).

The integration of distributed energy Resources (DERs) equipped with smart energy technologies into the distribution network benefits society both sociologically and economically, while ensuring the stability and reliability of the electricity distribution network operators. As we continue to integrate increasing DERs technologies into the system, the existing EDS structure needs to be synchronized with this change due to the landscape created by these variable generation sources (Department of Energy, 2015).

Since the existence of EDSs, the structure has been dependent on centralized large generation sources. However, with new technologies and developments, this structure is shifting to a dynamic paradigm. In the last 20 years, many DERs such as photovoltaic systems (PV), variable wind generators, electric vehicles (EV), fuel cells, energy storage systems (ESS), demand response and load shifting resources have been integrated into the existing grid (Arboleya et al., 2022).

However, the current power grid is not designed to handle these unpredictable load flows, which can cause system congestion and high peaks, known as the "duck curve" in many countries(Calero et al., 2022). The negative effects of high DERs penetration have been observed where oversupply causes negative pricing more than 100 times a year (Reed, 2017). In such cases, the typical solution to curtail renewable energy production has been shown to lead to uneconomic and zero-carbon electricity losses (Hussain et al., 2023).

Additionally, these new loads and DERs are extremely important to help balance supply-demand between generation and consumption and provide EDS with a flexible operating tool. However, there are many flexibility methods that are applied without considering the criteria to ensure the operational integrity of the EDS (Arboleya et al., 2022).

Maximizing the hosting capacity (HC) of electrical distribution systems (EDS) for DERs is an integral part of efforts to increase the share of renewable energy sources (RES) in electricity grids (Toghranegar et al., 2022).

This study examines the status of technologies available on the grid that can be developed for applications that provide greater system flexibility, including flexible generation and customer-focused distributed resources (Department of Energy, 2015).

Electricity Distribution System Flexibility

Due to the significant penetration of RES, traditional operating methods have been recognized as insufficient to meet fluctuations in net load (Kaheh et al., 2019). Flexibility has therefore emerged as a critical consideration in the design of future power systems dominated by RES.

The International Energy Agency (IEA) defines energy flexibility as "the ability of a building to manage its demand and generation in response to local climatic conditions, user needs and grid requirements"(Hussain et al., 2023). System flexibility is also defined as the need for the electricity system to adjust generation (generation flexibility) or consumption (demand side flexibility) to maintain a secure system operation, taking into account grid stability constraints and intermittent renewable energy resources(Freire-Barceló et al., 2022). Flexibility can also be defined as "a power system that can manage variability and uncertainty in both generation and demand while maintaining a satisfactory level of reliability at a reasonable cost over different time horizons". From these definitions, we can generally say that resilience refers to the capacity of an EDS to reliably maintain supply during temporary and large imbalances (Hussain et al., 2023).

Flexible DERs connectivity is expected to provide a service that can respond quickly to demands on the grid, providing additional energy to the grid when it is most needed. We can basically categorize flexibility resources as DERs, energy storage, consumer-side dispatchable loads and virtual flexibility solutions (Alizadeh et al., 2016).

Flexible Resources

Flexible DERs can adjust the consumption or generation of electricity at a specific location on the grid for a given period of time.

These include;

- Flexible generation resources (Electric vehicles, loads that can be changed or shortened over time (SL/CL), Combined heat and power (CHP) units, systems setting power supplied by distributed generation (DG) that can be distributed such as PV, wind)
- Flexible storage resources (Energy storage systems, including battery energy storage (BES), V2G technology)
- Flexible consumption sources (Replaceable residential loads represent loads whose use can be scheduled on demand. For example, irons, washing machines and dishwashers, air conditioners, heaters and coolers, etc.). Figure 1 shows the providers of flexibility services (Freire-Barceló et al., 2022).

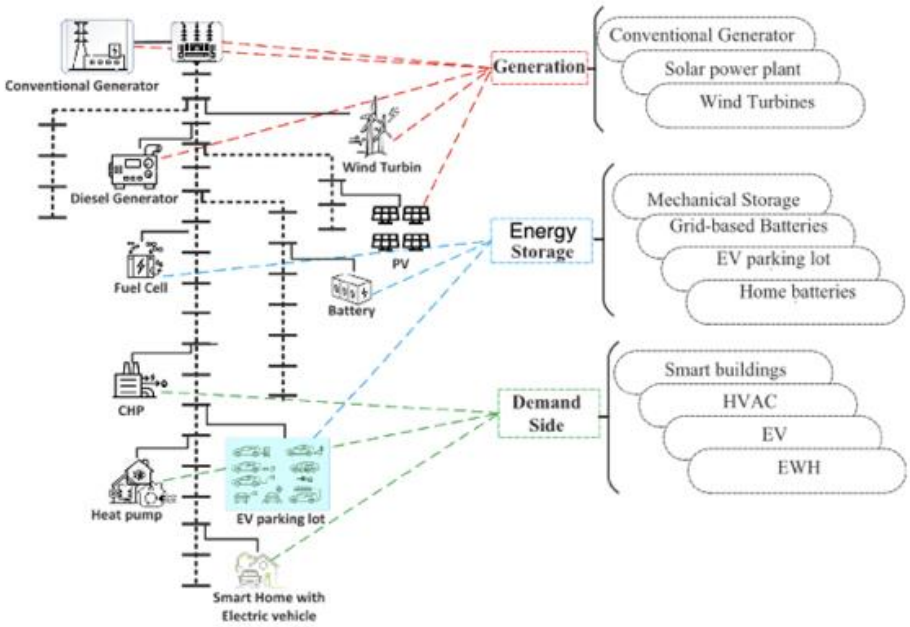

Figure 1. Flexible energy source types

In the literature, grid-connected flexible resource types are divided into three categories as mentioned above. Distributed generation, bidirectional DERs and electricity consumption.

Each option includes different flexibility models in the EDS and therefore each category requires separate processing. Energy demand-side flexibility provides downstream flexibility, while DERs provide upstream flexibility. ESSs provide bi-directional flexibility, offering a wider variety of implementations.

Although these three types of different energy systems proposal a range of grid flexibility, their potential is under-utilized (Pearson et al., 2022).

The graph in Figure 2 shows the ideal load profile and its upward and downward elasticities. In this way, we can see downward as a situation where consumption is more and generation is less, and upward as a situation where generation is more and consumption is less. Desired load profile for distribution system operator (DSO) is a situation with less fluctuation and uncertainty.

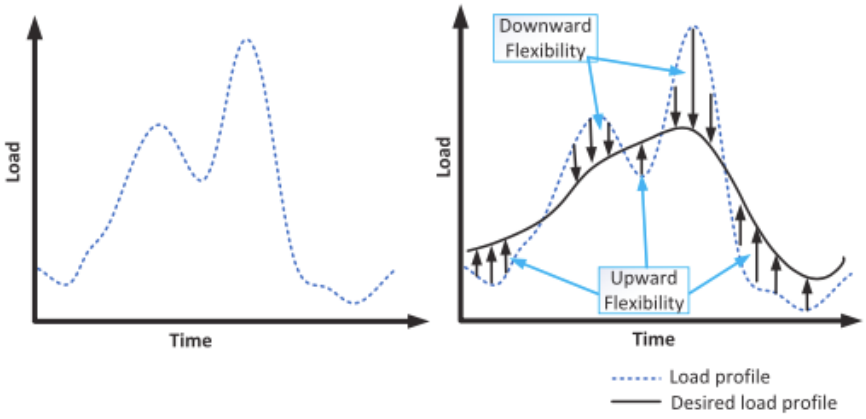

Figure 2. Flexibility concept from production and consumption

The basic service in power systems is to ensure the balance between generation and consumption by securing the frequency of the system(Pedro et al., 2023). For the desired load profile, a more secure system can be created by utilizing both generation flexibility and consumption flexibility.

Flexible Connection Applications

When integrating the increasing amount of DERs into the EDS, the traditional approach of fit and forget is adopted. In fact, this approach only allows DERs to be integrated into the EDS up to a certain level in order to maintain system operational security and integrity. However, this approach prevents the flexibility potential of DERs from being used efficiently. The fit-and-forget policy can also be interpreted as avoiding over-sizing the grid to cope with reverse energy flows and capacity increases in the EDS(Silva et al., 2021). For the integration of more DERs, this approach will not be environmentally and economically efficient. DSOs should therefore go beyond this policy by taking advantage of DERs flexibility and introducing new operating models and innovations (Pearson et al., 2022).

The increasing need for flexible resources in electricity systems has led to the need to explore different flexibility mechanisms. One of the mechanisms that is becoming increasingly common in the EU is connection agreements, also called flexible connection. EDSs allow network users to establish off-premise network access.

For example, in the Walloon region of Belgium, all new DERs over 250 kVA are required to make flexible connections. In Germany, a 3% curtailment rule applies to all DERs connections to EDS.

In the UK, Electricity North West DSO offers some flexible connection options for generation and consumption customers and is working on additional offers for system security (Nouicer et al., 2023).

The iPower project established a " trade room" for local flexibility trading at the EDS level in Germany (IPower, 2009).

The PeerEnergyCloud project focused on building a virtual market platform of a microgrid for electricity trading in Germany and established a cloud-based energy trading system for excess generation (Soto et al., 2021).

The ECO-Grid project created a prototype of a future smart energy system in Europe with the aim of leveraging market forces and smart power consumption management to involve individual consumers in balancing an energy system with abundant renewable energy. But ECO-Grid EU' s plans also include the possibility of creating a "win-win" situation where small and large electricity customers can save money on their electricity bills while at the same time relieving the power system, reducing investments in grid reinforcements and new grids in the long term (Gantenbein et al., 2012).

The Piclo project aims to provide data visualization for consumers and to offer Italy's first local flexibility market with E-Distribuzione(Open Utility a Glimpes into the Future of Britain’s Energy Economy, n.d.).

The Empower project aimed to develop a local market Paradigm in Europe that includes three financial market platforms for local energy sales, local flexibility and trading of other services, enabling EDS to profit from the embedded flexibility of the user side. This project aimed to greatly enhance the positive impacts of DERs and improve the resilience and effectiveness of supply-demand programs (Local Electricity Retail Markets for Prosumer Smart Grid POWER Services, 2020).

As a different solution, techno-economic studies have also been proposed for local community solutions to assess the reliability of Demand Side Management (DSM), sizing grid assets or studying the suitability of technological solutions, by adopting smart operation solutions that derive flexibility from EDS connected consumption and generation assets. In the integration of flexibly connected DERs for long-term energy system planning through the Long Range Energy Alternative Planning (LEAP) project, taking into account different DSM strategies, types and levels for India with high DERs penetration (including both EE and peak load shifting), demonstrating cost savings of up to 18% and reductions in both total installed capacity and CO2 emissions of up to 10% and 23% respectively through the simultaneous implementation of both supply-side and demand-side flexibility (Couraud et al., 2023).

Flexible Connection Types

In practice, the DSO offers 5 different flexible connection types to the customer from the flexible connection types applied in the UK, Ireland by ENA (Energy network association), which has been adopted by other countries.

1) Scheduled buy/sell connections: These offer customers flexible connection to the grid, with energy purchases or sales limited to certain periods of the day, week, month or year. For example, on a day of peak PV generation, wind generation may be limited during the day.

2) 3rd Party flexible connections: Some customers may also consider joint capacity and demand management, both installed and managed by the customer.

3) Single Manufacturer Active Network Management (SGANM): Manages only one producer and up to two constraints instead of managing multiple constraints and multiple producers.

4) Limited Power Supply Connections: This type of flexible connection is also used in cases where the generation capacity is larger than the installed generation capacity injected into the EDS.

5) Limitation connections to energy import: These are used where the installed asset has a capacity to deliver energy from the EDS that is greater than the agreed energy that needs to be delivered.

Flexible Curtailment Methods

There are three different approaches to determining the curtailment of flexible connections to manage congestion in EDS, all three of which are deterministic and rule-based:

a) In the Last In First Out (LIFO) method, any binding grid constraint is solved by interrupting generators in the reverse order of their connection applications. In this way, generators are insulated against larger outages caused by other generators connecting after them, as shown in Figure 3.a).

Under Last In First Out (LIFO), each generation asset is assigned a position in the priority stack according to its application date.

When a new DERs makes a flexible connection, a queue is assigned according to the date of its inclusion in the system. This customer is evaluated according to this sequence for the duration of the connection agreement. In case of a curtailment in the EDS, the DSO determines the customer to be curtailed starting from the last row according to this sequence number. This means that in case of any curtailment, the lowest ranked customer will always be affected. With LIFO, the customer at the top of the queue is the least affected customer in the event of an outage at the EDS.

b) Pro-rata method, where the curtailment in the region of an affected flexible link is shared equally among all generators energizing during the congestion, as shown in Figure 3.b). Pro-rata curtailment solves constraints according to the proportional contribution of each generator.

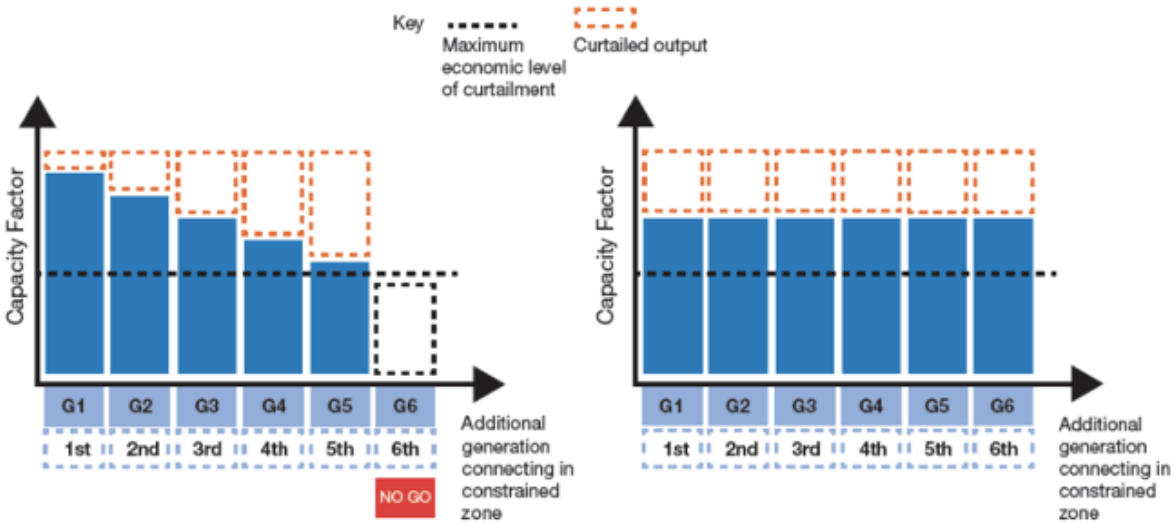

Figure 3. a) First-in last-out (LIFO) b) Pro-Rata graphical representation of applications

c) Curtailment Index, customers with a flexible connection to the EDS is given an estimated curtailment index. This index is used to determine the maximum outage duration that the customer will be affected in a year (Georgiopoulos et al., 2020). The DSO uses this index to determine the curtailment sequence, as shown in Figure 4.

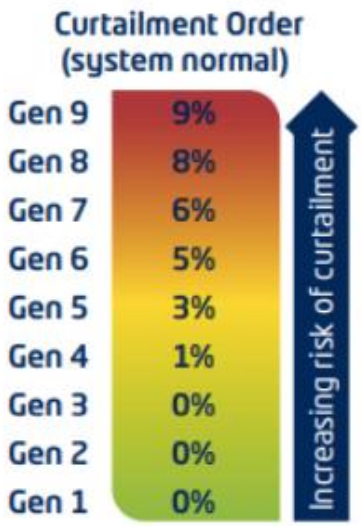

Figure 4. Curtailment index according to producers' participation

In consideration for a faster and cheaper connection, the customer is based on accepting a contractual requirement for remote, real-time switching of the usual power flows by the DSO through automation. The amount of modification or curtailment varies according to the connection agreement (ENA, 2021).

When flexibility is analyzed by connection agreements; when they compared demand side flexibility in distribution grid between voluntary and mandatory agreements, they concluded that voluntary agreements may have benefits in terms of prosperity gains and network investment savings, but mandatory load shedding should also be applied to save grid investment.

In both cases, they find that mandatory connection agreements lead to higher prosperity levels and significant grid investment savings than in the absence of explicit demand-side flexibility. While mandatory agreements are also more equitable among both generating consumers and passive consumers, there are concerns that they may face public backlash from consumers who do not like to be constrained (Nouicer et al., 2023).

Challenges and Limitations

As mentioned earlier, due to the remarkable proliferation of DERs, it has been recognized that traditional operating methods are insufficient to handle fluctuations in net load. Flexibility is therefore emerging as a critical consideration in the design of future EDS dominated by DERs. The main sources of flexibility in such systems include distributed generation facilities, flexible loads on the consumer side, virtual flexibility solutions and energy storage facilities (Alizadeh et al., 2016).

Technically, an EDS flexibility service can be defined as the adjustment of power from a specific location within the grid, at a specific time, for a specific period of time. A flexibility service is therefore a service characterized by five features. Direction, electrical composition in power, start time, duration, temporal characteristics defined by the location base (Freire-Barceló et al., 2022).

Traditionally, planning for the expansion and upgrading of the EDS contributes to the connection of more DERs. However, in order to develop techno-economically efficient plans, new tools are needed to better represent the current situation and new management mechanisms to integrate DERs are required (Alvarez et al., 2022).

Figure 5 shows the renewable energy contributions of NECPs member countries until 2030 according to the NECPs (National energy and climate plans) report. The NECPs association is committed to a policy of maintaining and strengthening world leadership in renewable energy. It sees this not only as a matter of system security and imperative climate change policy, but also as an industrial policy imperative to fully harness the growth potential of clean energy (European Commission, 2019). It is obvious that energy production from RESs will increase further in the coming decades. This increase will cause the problem of "overproduction" in the system. Therefore, the demands of DSO for the flexibility of the system will also increase.

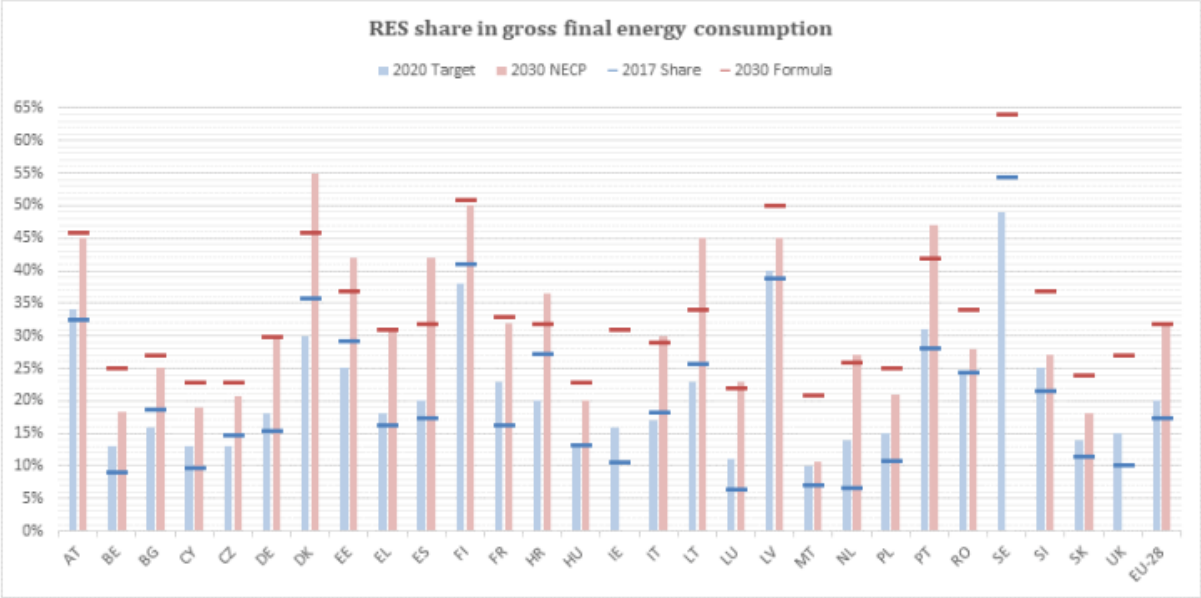

Figure 5. National renewable energy contributions.

It is normally accepted that energy demand is inflexible and must always be supplied. However, with the appearance of flexible assets, demand-side flexibility is expected to come to the fore. Demand-side flexibility brings with it the potential to realize the flexibility to improve energy efficiency and further reduce costs. Flexibility at the distribution level is defined in the literature as the provision of flexibility from distributed assets i.e., solving system congestion, minimizing power loss or voltage deviation.

One of the reasons why they are currently unable to exploit their flexibility potential is the current structure of the power system. Currently, energy storage facilities with high flexibility potential for load shifting, fast demand response, etc. can be integrated into the system (Pearson et al., 2022).

ESS represents a crucial component in the future flexibility portfolio, especially in terms of cost relative to other flexibility assets. Flexibility in EDS with ESS provides three important benefits;

1) By improving the utilization of generation from intermittent renewable energy, it enables low-carbon generation capacity,

2) Provides lower-cost system stabilization during peak times when energy usage is high, replacing more expensive flexibility options.

3) Improves utilization of existing conventional generation and postpones investments in transmission and distribution grid capacity expansion (Sanders et al., 2016).

A study in the UK estimated the cost of reinforcing the grid to connect more DERs to the system at a budget of £2.7 billion per year. However, the UK concluded that using flexibility technologies could save the electricity system £17-40 billion between now and 2050 (Sanders et al., 2016). Furthermore, the use of flexibility technologies typically increases HC and grid access by 50-100%, maximizing DERs interconnection share and minimizing operational constraint (ENA, 2021).

Taking flexibility into account will contribute to reducing renewable system investment costs. Adoption of renewable systems will primarily depend on the reduction in ESS costs. The highest levels of savings will be achieved by reducing ESS-related costs. Improving the grid by allowing more energy to be imported during periods when wholesale energy prices are cheaper would be economically beneficial.

Conclusion

The aim of this paper is to investigate the concept of flexibility, which is an important aspect in increasing the HC and management of DERs.

High penetration scenarios of DERs are known to cause difficulties for existing grids and will therefore create demand for advanced control concepts to guarantee reliable and cost-effective grid operation in the future (Von Appen et al., 2013).

This requires local, decentralized and centralized strategies, as well as more fully integrated approaches that consider technical effectiveness and economic efficiency for all stakeholders.

Flexibility can also provide "optionality", whereby additional investments in flexibility can defer decision-making on larger investments until better information is available, thereby reducing the need to make potentially regrettable decisions.

While much research and projects on flexibility have been mentioned in this paper, it is still under-represented in actual practice. There are many issues related to flexibility that need to be researched. These include;

- Integration costs of DERs into the grid,
- How to manage all flexible assets simultaneously (Freire-Barceló et al., 2022),
- Determination of flexibility parameters to be included in the distribution system,
- To facilitate flexibility management and deployment at the distribution level, standardized definitions of the distribution assets required for flexibility need to be established,
- Transmission side impact,
- Further research should also include the development of a framework that incorporates the protection of the information barrier, i.e., taking into account both the different interests of participants and the system-wide perspective for transmission and distribution systems,
- The energy market, i.e., the development and definition of new marketplaces for participation in the intraday market (Pearson et al., 2022).

Future research exploring these important issues will enable full utilization of flexibility in EDS.

Finally, we can conclude that the definition of flexibility is subjective according to the party to be implemented and the context of the project (Hussain et al., 2023). However, whether flexibility is on the DERs side or on

the consumer side, it can contribute to the stability and reliability of the system and reduce costs, postponing the need for investment.

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FARKLI GÜÇTEKİ TERMOELEKTRİK JENERATÖRLERİN POTANSİYELİNİN DENEYSEL ARAŞTIRILMASI

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ÖZET

Günümüzde enerji ihtiyacını azaltma ve sıfır atık ısı yolunda birçok çalışma yapılmaktadır. Bu bağlamda çevreye atılan atık ısıyla tekrardan enerji elde etmek oldukça popüler bir çalışma alanıdır. Özellikle son yıllarda malzeme teknolojisindeki gelişmelerle birlikte termoelektrik jeneratörlere (TEJ) olan ilgi giderek artmaktadır. Termoelektrik jeneratörler ısıyı elektrik enerjisine çeviren cihazlardır. Ancak enerji dönüşümü sırasında bu cihazların verimlilikleri oldukça düşük kalmaktadır. Bu çalışma kapsamında farklı model termoelektrik jeneratörlerin farklı çalışma koşullarındaki performansları deneysel olarak araştırılmıştır. Bu amaç doğrultusunda farklı güçlere sahip termoelektrik jeneratörlerin farklı sıcaklıklarda sergiledikleri termal ve elektriksel performansları karşılaştırılmıştır. Çalışma sonucunda sıcak yüzey sıcaklığının artmasıyla tüm TEJ'lerin yüzeyleri arasındaki sıcaklık farkları ve dolayısıyla elektriksel çıktıları artmıştır. En yüksek güç çıktısı 150^0C sıcak yüzey sıcaklığında TEC12706 modelinde 1.80 W olarak elde edilirken en düşük güç çıktısı 50^0C sıcak yüzey sıcaklığında TEG12610-4.3 modelinde 0.04 W olarak elde edilmiştir. Verim açısından bakıldığında artan sıcaklıkla tüm modellerde verim artmıştır. Bu bağlamda en yüksek verim 150^0C sıcak yüzey sıcaklığında %4.33 ile TEC12706 modelinde elde edilmiştir. Bu çalışmayla farklı uygulama alanlarında atık ısıdan elektrik üretiminde doğru TEJ modelinin seçiminde bir fikir vermesi açısından literatüre katkı sağlanmıştır.

Anahtar Kelimeler: Termoelektrik jeneratörler, atık ısı, yenilenebilir enerji, optimizasyon

ABSTRACT

Today, many efforts are being made to reduce energy needs and achieve zero waste heat. In this context, obtaining energy again from waste heat released into the environment is a very popular field of study. Especially in recent years, interest in thermoelectric generators (TEGs) has been increasing with the developments in material technology. TEGs are devices that convert heat into electrical energy. However, the efficiency of these devices during energy conversion is quite low. Within the scope of this study, the performances of different models of TEGs under different operating conditions were experimentally investigated. For this purpose, the thermal and electrical performances of TEGs with different powers at different temperatures were compared. As a result of the study, as the hot surface temperature increased, the temperature differences between the surfaces of all TEGs and therefore their electrical outputs increased. The highest power output was obtained as 1.80 W in the TEC12706 model at a hot surface temperature of 150 °C, while the lowest power output was obtained as 0.04 W in the TEG12610-4.3 model at a hot surface temperature of 50 °C. In terms of efficiency, efficiency increased in all models with increasing temperature. In this context, the highest efficiency was obtained in the TEC12706 model with 4.33% at a hot surface temperature of 150 °C. This study contributed to the literature in terms of giving an idea on the selection of the appropriate TEG model in electricity production from waste heat in different application areas.

Keywords: Thermoelectric generators, waste heat, renewable energy, optimization.

GİRİŞ

Gün geçtikçe artan enerji talebini karşılama ve çevre kirliliği artışını önlemek adına birçok çalışma yapılmaktadır. Yenilenebilir enerji kaynaklarından enerji üretimine ek olarak alternatif enerji kaynaklarından daha ekonomik ve daha çevreci yöntemler ile enerji üretimi üzerine çalışmalar giderek artmaktadır. Bu çalışmalar içerisinde TEJ'ler son zamanlarda oldukça önemli bir yer tutmaktadır. TEJ'ler esasında Seebeck etkisini kullanarak ısıyı elektrik enerjisine dönüştüren cihazlardır. Bir TEJ yalıtkan görevi gören iki adet seramik plaka arasına yerleştirilmiş p ve n tipi yarı iletken elemanlardan ve bu yarı iletkenleri elektriksel olarak seri, termal olarak paralel bağlayan bakır elektrotlardan meydana gelmektedir. Seramik plakalar arasında sıcaklık farkı meydana geldiğinde elektronların sıcaktan soğuğa doğru hareket etmesiyle bir voltaj farkı meydana gelir ve TEJ eğer bir elektriksel devreye bağlıysa bu devreden doğrusal akım geçmeye başlar [1].

TEJ'ler hareketsiz sistem içerisinde sessizce çalışır [2]. Geleneksel enerji üretim yöntemlerine göre çeşitli avantajlar sundukları için giderek daha popüler hale gelmektedir. TEJ'lerin ana avantajlarından biri yüksek verimlilikleridir. Aldıkları termal enerjinin %10'a kadarını elektrik enerjisine dönüştürebilirler. Bu, tipik olarak yaklaşık %30 verime sahip olan içten yanmalı motorlar (ICE'ler) gibi geleneksel enerji üretim yöntemlerinin verimliliğinden önemli ölçüde daha yüksektir [3]. Diğer enerji üretim teknolojileriyle karşılaştırıldığında termoelektrik jeneratörler basit yapılı, güvenilir, sessiz ve stabil çalışma, bakım gerektirmeme, hareket eden parçalarının olmaması ve uzun ömürlü olması gibi avantajlara sahiptir. Isı kaynağının olduğu bir noktada zor şartlar altında bile olsa uzun süre boyunca gözetimsiz bir şekilde çalışabilir ve yağmur, kar gibi hava koşullarından etkilenmezler [4]. TEJ'ler ayrıca herhangi bir emisyon veya kirletici madde üretmedikleri ve güneş veya jeotermal enerji gibi yenilenebilir kaynaklarından elektrik üretiminde kullanılabildikleri için çevre dostudur.

TEJ'lerin bazı sınırlamaları vardır. Güç üretmek için bazı uygulamalarda elde edilmesi zor olabilen önemli bir sıcaklık farkına ihtiyaç duyarlar. Ayrıca, üretimleri nispeten pahalıdır ve verimlilikleri, geleneksel enerji üretim yöntemleriyle rekabet edecek kadar yüksek değildir [5]. Bu sebeple henüz geniş çapta benimsenmemiştir.

TEJ'leri optimize etmenin birkaç yolu vardır Bunlardan birisi verimliliklerini artırmaktır. Bir TEJ'in verimliliği, elektrik güç çıkışının termal güç girişine oranı olarak tanımlanır. TEJ'lerin verimliliğini arttırmanın en yaygın yolu, TEJ'in sıcak ve soğuk tarafları arasındaki sıcaklık farkını arttırmaktır [6]. Bu, birim sıcaklık farkı başına üretilen voltajın bir ölçüsü olan daha yüksek Seebeck katsayısına sahip malzemeler kullanılarak yapılabilir. TEJ'leri optimize etmenin bir başka yolu da termal dirençlerini azaltmaktır. Termal direnç, TEJ'in sıcak ve soğuk tarafları arasındaki sıcaklık farkının, TEJ'den geçen ısı akışına oranı olarak tanımlanır [7]. Termal direnci azaltmanın en yaygın yolu, TEJ'den geçen ısı akışını arttırmaktır. Bu, TEJ'in yüzey alanını artırarak veya daha yüksek termal iletkenliğe sahip malzemeler kullanarak yapılabilir. TEJ'ler üretim maliyetleri düşürülerek te optimize edilebilir. Bunu yapmanın bir yolu daha ucuz malzemeler kullanmak, diğer yolu ise 3D baskı veya nano teknoloji gibi yeni bir üretim süreci kullanmaktır [8, 9]. Bunlara ek olarak, kararlı durum ve geçici koşullar gibi farklı yükleme koşulları altında TEJ'lerin davranışları incelenerek optimal bir tasarım elde edilebilir [10]. Bu, TEJ'lerin farklı çalışma koşulları altındaki davranışını tahmin etmeye ve tasarımlarını belirli uygulamalar için optimize etmeye yardımcı olabilir.

TEJ'ler istenilen özelliklerin bağdaştığı noktada olup yüksek maliyetli ve düşük verimli sistemlerin ötesinde ilgi çeken bir konumda yer almaktadır. Ekonomik açıdan farklı bir perspektifte bakıldığında iş sahasına yakıt ulaştırmanın zor olduğu noktalarda TEJ'ler uygun bir enerji kaynağı olma potansiyeline sahiptir [11]. Diğer yönden halihazırda enerji üreten sistemlerin verimini arttırmada da kullanılabilirler.

TEJ'ler geniş bir uygulama yelpazesine sahip olmakla birlikte yüksek verimlilikleri ve çok yönlülükleriyle giderek daha popüler hale gelmektedirler. TEJ'lerin kullanıldığı ana alanlardan birisi elektrik üretimidir. Özellikle uzak konumlarda veya geleneksel güç üretim yöntemlerinin mümkün olmadığı ortamlarda kullanışlıdırlar. Güneş enerjisi, jeotermal ve endüstriyel proseslerden kaynaklanan atık ısı gibi çeşitli kaynaklardan güç üretmek için kullanılabilirler. Bu kaynaklardan elde edilen güç ile akıllı telefonlar ve dizüstü bilgisayarlar gibi küçük elektronik cihazların yanı sıra enerji santralleri gibi daha büyük sistemler için alternatif bir enerji kaynağı olabilirler [11]. TEJ'lerin kullanıldığı bir diğer alan da otomobillerdir. TEJ'ler, motor tarafından üretilen atık ısıdan güç üretmek için otomobillere entegre edilebilir [12]. Bu durum TEJ'lerin aracın genel verimliliğini artırmaya ve emisyonlarını azaltmaya yardımcı olma potansiyelini ortaya çıkarmaktadır. TEJ'ler ayrıca hibrit ve elektrikli araçlarda menzil artırmaya yönelik yardımcı bir eleman olarak ta

kullanılmaktadır [13]. Diğer taraftan TEJ'ler binalarda atık ısıdan güç üretmek içinde kullanılmaktadır. HVAC sistemleri ile binanın enerji tüketimini ve maliyetlerini azaltmaya yardımcı olma potansiyeline sahiptirler [14]. Bunun yanında endüstriyel proseslerdeki atık ısıyı geri kazanarak faydalı enerjiye dönüştürebilirler. Bu bağlamda atık ısıyı geri kazanmak ve güç üretmek için çelik yapımı, cam üretimi ve çimento üretimi gibi proseslerde kullanılabilirler. Böylece sürecin genel verimliliğini artırmaya ve emisyonları azaltmaya olumlu yönde katkı sağlamaktadırlar [15]. Bu uygulamalara ek olarak, TEJ'ler ayrıca taşınabilir güç, uzay ve havacılık, petrol ve gaz ve kablosuz sensör ağları gibi çeşitli başka uygulamalarda da kullanılabilir [16]. Sonuç olarak TEJ'ler enerji üretiminden otomobillere, binalara, endüstriyel süreçlere ve daha pek çok alanda geniş bir uygulama yelpazesine sahiptir. Yüksek verimlilikleri, çok yönlülükleri ve hareketli parçaların bulunmaması, onları geleneksel güç üretim yöntemlerinin uygulanabilir olmadığı çeşitli uygulamalar için güvenilir ve çekici bir seçenek haline getirmektedir.

Sonuç olarak, TEJ'ler termal enerjiyi elektrik enerjisine dönüştürmenin oldukça verimli ve güvenilir bir yoludur. Çok çeşitli uygulamalarda kullanılabilir ve diğer sistemlere entegre edilebilirler. Bu çalışmada da farklı sıcak yüzey sıcaklıklarında farklı güçteki TEJ'lerin elektrik üretim performansları karşılaştırılarak uygulamada sahip olduğu potansiyel ortaya çıkarılmaya çalışılmıştır.

MATERYAL ve TÖNTEM

Bu çalışmada termoelektrik jeneratörlerin hangi şartlarda daha verimli çalıştığı tespit edilip bu çalışma şartları altında farklı güçteki TEJ'lerin elektriksel performanslarını karşılaştırmak için deneysel yöntemlerden yararlanılmıştır. Deneysel çalışmada piyasadan temin edilen farklı güç ve çalışma koşullarına sahip termoelektrik jeneratörler (TEG12610-4.3, TEG12610-5.1, TEC12706) kullanılmıştır. Deneylerde TEJ'lerin elektrik üretimi için ihtiyaç duyulan sıcaklık farkı fan ile aktif olarak soğutulan ısı borulu ve alümiyum kanatçıklı soğutma bloğu kullanılarak elde edilmiştir. Tüm deneyler boyunca fan devri ve ortam sıcaklığı sabit tutulmuştur. Akım ve güç çıktılarını elde etmek için TEJ'lere 5.4 Ω büyüklüğünde bir yük direnci bağlanmıştır. Bu şartlar altında TEJ'ler farklı sıcak yüzey sıcaklıklarına (50^0C, 100^0C ve 150^0C) maruz bırakılarak elektriksel çıktılar elde edilmiştir. 150^0C sınırı TEJ'ler arasında çalışma sıcaklığı en düşük modele göre belirlenmiştir. Yüzey sıcaklıkları istenilen değerlere ayarlanabilir bir ısıtıcı tabla kullanılarak getirilmiştir. Yüzey sıcaklıkları TEJ'in sıcak ve soğuk yüzeylerinde k tipi temokupllar bağlanarak ölçülmüştür. TEJ'in soğutma sistemiyle ve ısıtıcı tablayla temas ettiği yüzeylerde ısı transferi kaybını en aza indirmek için ticari bir termal macun kullanılmıştır. Elektriksel çıktılar TEJ'in uçlarına seri ve paralel bağlanmış multimetreler ile ölçülmüş ve kaydedilmiştir. Aynı şekilde TEJ'in sıcak yüzeyinde istenilen sıcaklığı elde etmek için gerekli olan güç girdisi ısıtma tablasına bağlı multimetreyle okunan akım ve voltaj değerleriyle hesaplanmıştır.

TEJ'den R yük direnci bağlıyken elde edilen güç çıktısı P aşağıdaki gibi ifade edilir:

$$P = I^2 R = VI \tag{1}$$

Bu denklemde V kapalı devre voltajını, I ise akımı göstermektedir. TEJ'in verimi ise üretilen gücün (P), giren ısıl güce (Q_g) oranıyla hesaplanır. TEJ'in verimi (2) numaralı denklemde verilmiştir.

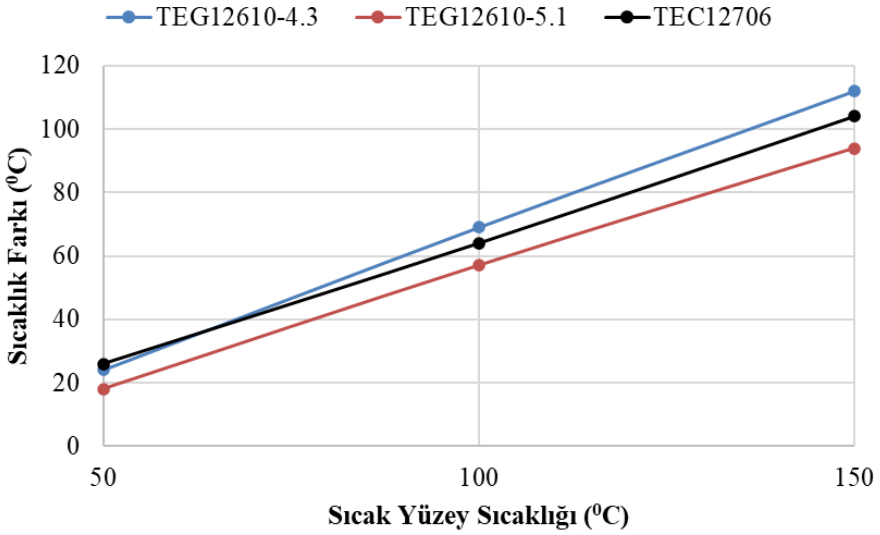
$$\eta = \frac{P}{Q_g} = \frac{I^2 R_L}{Q_g} \tag{2}$$

BULGULAR

Çalışma kapsamında farklı sıcak yüzey sıcaklıklarında farklı model TEJ'lerin elektriksel performansları karşılaştırılmış ve optimal çalışma koşulları belirlenmiştir. Bu bağlamda TEJ'lerden elde edilen sıcaklık farkı, akım, voltaj, güç ve verim çıktılarının sıcak yüzey sıcaklığına bağlı değişim grafikleri çalışma içerisinde verilmiştir.

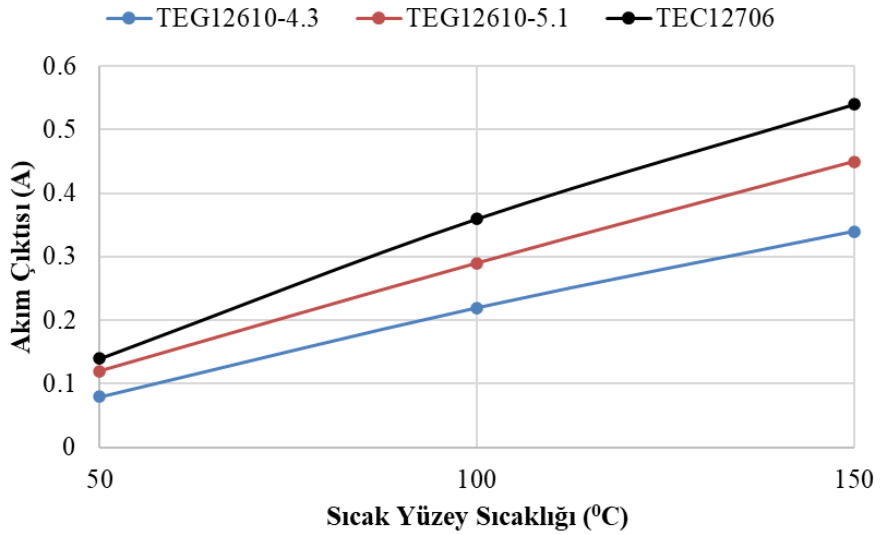
Farklı güçteki TEJ'lerin yüzeyleri arasındaki sıcaklık farkının sıcak yüzey sıcaklığına bağlı değişimi Şekil 1'de verilmiştir. Her üç modelde de sıcak yüzeyin artışıyla sıcaklık farkları artmıştır. Düşük sıcaklıkta TEG12610-5.1 ve TEC12706 modellerinde elde edilen sıcaklık farkları birbirine çok yakın olsada sıcaklığın artmasıyla bu

değerler arasındaki farkta giderek artmıştır. Bu bağlamda en düşük sıcaklık farkı 50^{0}C sıcak yüzey sıcaklığında TEG12610-5.1 modelinde 18^{0}C olarak elde edilirken en yüksek sıcaklık farkı 150^{0}C sıcak yüzey sıcaklığında TEG12610-4.3 modelinde 112^{0}C olarak elde edilmiştir. Genel olarak bakıldığında en düşük sıcaklık farklarına TEG12610-5.1 modelinde, en yüksek sıcaklık farklarına TEG12610-4.3 modelinde ulaşılmıştır.



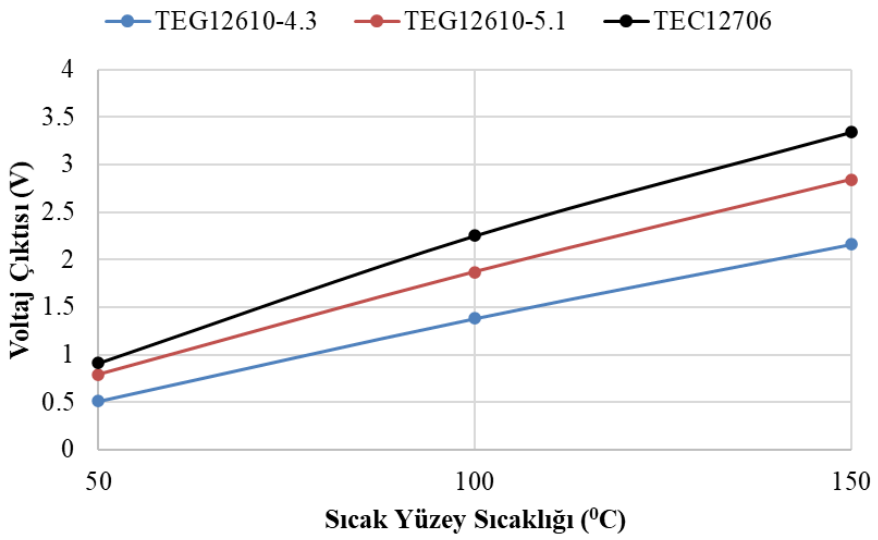
Şekil 1. Farklı güçteki TEJ'lerin yüzeyleri arasındaki sıcaklık farkının sıcak yüzey sıcaklığına bağlı değişimi

Farklı güçteki TEJ'lerin akım çıktılarının sıcak yüzey sıcaklığına bağlı değişimi Şekil 2'de verilmiştir. Tüm modellerde sıcak yüzey sıcaklığının artmasıyla akım çıktıları yükselmiş ve aynı sıcaklık değeri için modeller arasındaki akım farklarıda artmaya devam etmiştir. Genel olarak bakıldığında en yüsek akım çıktılarını TEC12706 modeli, en düşük ise TEG12610-4.3 modeli vermiştir. Bu bağlamda en düşük akım çıktısı 50^{0}C sıcak yüzey sıcaklığında 0.08 A, en yüksek akım çıktısı ise 150^{0}C'de 0.54 A olarak ölçülmüştür.



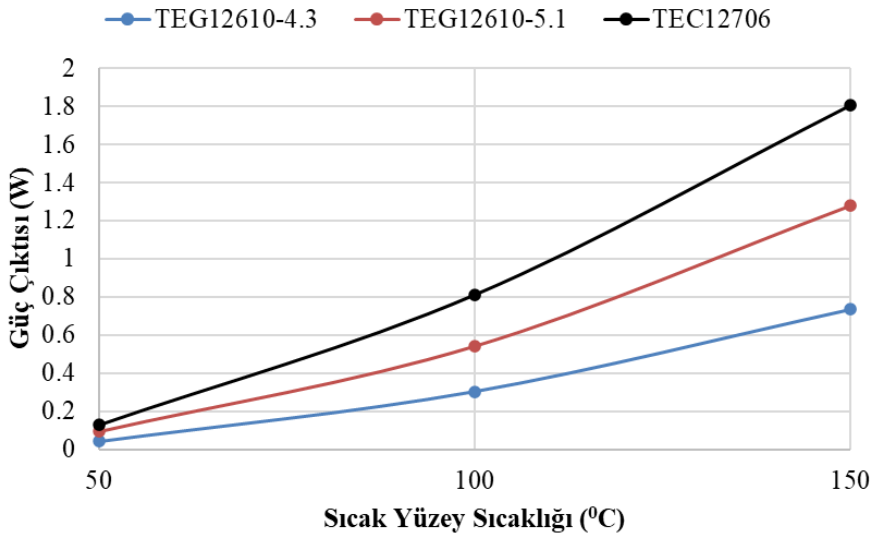
Şekil 2. Farklı güçteki TEJ'lerin akım çıktılarının sıcak yüzey sıcaklığına bağlı değişimi

Farklı güçteki TEJ'lerin voltaj çıktılarının sıcak yüzey sıcaklığına bağlı değişimi Şekil 3'de verilmiştir. Akım çıktılarında olduğu gibi voltaj çıktılarıda sıcak yüzey sıcaklığının artmasıyla yükselmiştir. Aynı sıcak yüzey sıcaklığında TEJ modelleri arasındaki voltaj farklarıda artmaya devam etmiştir. Genel olarak bakıldığında en yüksek voltaj çıktıları TEC12706 modelinde, en düşük ise TEG12610-4.3 modelinde elde edilmiştir. Bu bağlamda en düşük voltaj çıktısı 50^{0}C sıcak yüzey sıcaklığında 0.51 V, en yüksek 150^{0}C'de 3.34 V ölçülmüştür.



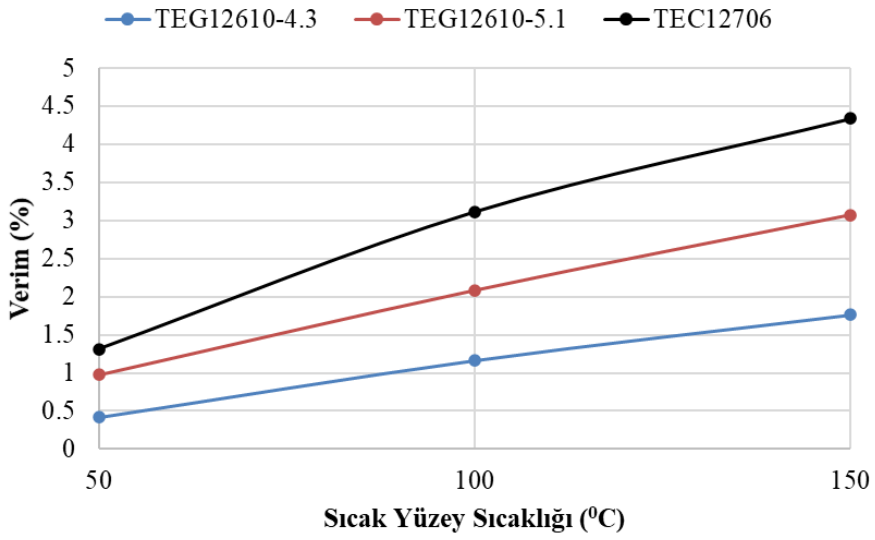
Şekil 3. Farklı güçteki TEJ'lerin voltaj çıktılarının sıcak yüzey sıcaklığına bağlı değişimi

Farklı güçteki TEJ'lerin güç çıktılarının sıcak yüzey sıcaklığına bağlı değişimi Şekil 4'de verilmiştir. Güç değerleri akım ve voltaj değerlerinin çarpılmasıyla elde edilmiş olup sıcak yüzey sıcaklığının artmasıyla güç çıktılarıda akım ve voltaj çıktılarına göre nisepeten artan bir trend çizgiyle artmıştır. TEC12706 güç çıktısı açısından tüm sıcaklıklarda daha iyi bir performans verirken, TEG12610-4.3 modeli en kötü performansı vermiştir. En yüksek güç çıktısı 150^{0}C'de TEC12706 modelinde 1.80W olarak hesaplanırken, en düşük ise 50^{0}C'de TEG12610-4.3 modelinde 0.04 W olarak hesaplanmıştır.



Şekil 4. Farklı güçteki TEJ'lerin güç çıktılarının sıcak yüzey sıcaklığına bağlı değişimi

Farklı güçteki TEJ'lerin verimlerinin sıcak yüzey sıcaklığına bağlı değişimi Şekil 5'de verilmiştir. Tüm modellerde sıcaklık artışıyla verimler de azalan bir formda artmıştır. Daha önceki sonuçlardan da anlaşılabildiği üzere daha düşük sıcaklık farkında en iyi elektriksel çıktıları veren TEC12706 modeli tüm sıcak yüzey sıcaklıklarında daha yüksek verim değerlerine ulaşmıştır. Diğer taraftan en yüksek sıcaklık farklarının elde edildiği halde en düşük elektriksel çıktıların meydana geldiği TEG12610-4.3 modeli tüm yüzey sıcaklıklarında en düşük verim değerlerini vermiştir. Düşük sıcaklıklarda tüm modeller birbirine yakın verimlere sahipken, sıcaklığın artmasıyla verim değerleri arasındaki fark modeller arasında giderek artmıştır. Sonuç olarak en yüksek verim değeri TEC12706 modelinde 150^{0}C'de %4.33 olarak hesaplanmıştır. En düşük verim değeri ise 50^{0}C'de TEG12610-4.3 modelinde %0.42 olarak hesaplanmıştır.



Şekil 5. Farklı güçteki TEJ'lerin verimlerinin sıcak yüzey sıcaklığına bağlı değişimi

TARTIŞMA

Literatürdeki çalışmalarda genellikle ısı alıcıların TEJ performansına etkisi üzerinde yoğunlaşılmıştır. Mohiuddin ve ark. [17] TEJ sisteminin performansı üzerine yaptıkları çalışmada sıcak ve soğuk yüzeyler arasındaki sıcaklık farkının arttıkça güç çıktısınında arttığını tespit etmişlerdir ve dikdörtgen kanatlı ısı alıcının dairesel kanatlı ısı alıcıya göre ısı transferinde daha verimli olduğunu saptamışlardır. Nazzal ve ark. [18] çalışmalarında alaşımlı ısı alıcıların TEJ performansı üzerindeki etkisini araştırmışlardır. Çalışmalarında bakır-alüminyum, bakır, berilyum-alüminyum olmak üzere üç farklı alaşım kullanmışlardır. Çalışmalarının sonucunda saf alüminyuma alternatif olarak bakır-alüminyum alaşımının kullanılabileceğini belirtmişlerdir. Li ve ark. [19] bir TEJ ve iki sıvı soğutucudan oluşan bir TEJ sistemi kurmuşlardır. TEJ'i bu iki sıvı soğutucu arasına monte etmişlerdir. Akışkan hızının sıcaklık dağılımı üzerinde önemli bir etkiye sahip olduğunu gözlemlemişlerdir. Mostafavi ve Mahmoudi [20] daha iyi ısı transfer performansı için TEJ'in sıcak ve soğuk yüzeylerinde kanatçık kullanarak bir TEJ sistemi oluşturmuşlardır. Sonuç olarak en yüksek güç çıktısını teorik olarak 3.4 W, deneysel olarak 2.8 W bulmuşlardır. Naphon ve ark. [21] A, B ve C olmak üzere 3 farklı su bloğu modeliyle entegreli termoelektrik soğutma modülünün soğutma performansını deneysel ve nümerik olarak incelemişlerdir. Nümerik sonuçların deneysel sonuçlarla iyi bir uyum içinde olduğunu ve C modelinin en iyi soğutma performansını verdiğini tespit etmişlerdir. Luo ve ark. [22] nümerik model ve termal direnç modeli kullanarak hava ve suyla entegre olan TEJ sisteminin performansını incelemişlerdir. Uygun koşullar altında termal direnç modelinin kabul edilebilir sonuçlar verdiği ancak nümerik modelin daha doğru sonuçlar için kullanılabileceği sonucuna varmışlardır.

Literatürde yapılan araştırmalarda farklı güçlere sahip TEJ'lerin optimum şartlarının belirlenmesi üzerine çalışmalar oldukça sınırlı sayıdadır. TEJ'ler üzerinde yapılan deneysel çalışmaların sınırlı sayıda bulunması da literatürdeki en büyük eksikliktir. Bu çalışmayla literatürdeki bu eksikliğin giderilmesi hedeflenmektedir.

SONUÇLAR

Çalışma kapsamında farklı güçteki TEJ'lerin farklı sıcak yüzey sıcaklıklarında sergiledikleri elektriksel performanslar deneysel olarak karşılaştırılmıştır. TEJ'ler için gerekli sıcaklık farkları soğuk yüzeye monte edilen ve fan ile aktif olarak soğutulan ısı borulu ve alüminyum kanatçıklı soğutma bloğu kullanılarak elde edilmiştir. Yapılan bu araştırma neticesinde elde edilen çıkarımlar aşağıda verilmiştir.

- Sıcak yüzey sıcaklığının artmasıyla birlikte TEJ'in ürettiği akım, voltaj, güç çıktıları ve verimleri artmıştır.
- Düşük sıcak yüzey sıcaklıklarında incelenen üç TEJ modelide birbirine yakın performanslar sergilemiştir. Bu durum düşük sıcaklıkların meydana geldiği uygulamalarda daha ekonomik TEJ modelinin tercih edilebileceğini ortaya çıkarmıştır.
- Sıcak yüzey sıcaklıklarının artmasıyla TEJ'lerin elektriksel çıktıları ve verimleri arasındaki farklar giderek artmıştır. Bu bağlamda yüksek sıcaklık değerlerinde TEC12706 modeli diğerlerine göre daha üstün bir performans sergilemiştir.
- TEC12706 modeli daha düşük sıcaklık farkında daha yüksek elektriksel çıktılar verirken TEG12610-4.3 modeli daha yüksek sıcaklık farkında daha düşük elektriksel çıktılar vermiştir. Bu özellik TEG12610-4.3 modelinin en düşük verime sahip olmasına sebep olmuştur.
- Tüm grafikler incelendiğinde daha yüksek sıcaklıklarda TEJ'lerin daha yüksek elektriksel çıktılar verebileceği ve verimlerinin belli bir noktaya kadar artmaya devam edebileceği tespit edilmiştir.

TEŞEKKÜR

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SİLİNDİRİK BİR LİYUM-İYON PİLİNİN FARKLI DEŞARJ ORANLARINDAKİ TERMAL VE ELEKTRİKSEL DAVRANIŞIN NÜMERİK İNCELENMESİ

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ÖZET

Ulaşım amaçlı ve hayatımızın vazgeçilmez bir parçası olan motorlu taşıtların sayısı dünya nüfusuyla orantılı olarak artmaktadır. Bu araçların yaydığı zehirli gazlar hem çevreyi kirletmekte hem de insan sağlığını tehdit etmektedir. Bu durum bilim insanlarının çevre dostu ve temiz enerji kaynaklı araçlar üzerine çalışmalarını arttırmıştır. Gelişen teknolojiyle ve yenilenebilir enerjiye daha fazla önem verilmesiyle birlikte bu sorunu hafifletmek ve yayılan zehirli gaz miktarını kontrol altına almak için içten yanmalı motorların yerini hibrit elektrikli motorlar ve elektrikli motorlar almaya başlamıştır. Bu motorların ihtiyaç duydukları güç, çok sayıda pil hücresinden oluşan batarya modülleri tarafından karşılanmaktadır. Batarya modülünden çekilen güç miktarının artmasıyla pillerin ve dolayısıyla batarya modülünün sıcaklıklarıda artmaktadır. Bu durum pil hücresinde kapasite ve performans kaybına sebep olmaktadır. Bu bağlamda etkili ve uygun batarya soğutma sistemlerinin geliştirilmesinde pillerin farklı deşarj oranlarında sergiledikleri termal ve elektriksel davranışların bilinmesi gerekmektedir. Bu çalışmayla silindirik bir lityum pil hücresinin farklı deşarj oranlarında sergilediği termal ve elektriksel davranış nümerik olarak incelenmiştir. Nümerik modelleme fluent paket programı içerisinde yer alan Çift Potansiyel Çok Ölçekli Çok Alanlı (MSMD) pil modeli kullanılarak gerçekleştirilmiştir. Deşarj oranının artmasıyla birlikte pil hücresinin sıcaklığı artmış ve gerilim değeri azalmıştır. Bu bağlamda en yüksek hücre sıcaklığı 1C deşarj oranında 56°C, en düşük hücre sıcaklığı ise 0.25C'de 28.7^{o}C olarak elde edilmiştir. Diğer taraftan pil hücresi gerilimi 1C deşarj oranında 0.8-0.9 V ve 0.25C'de ise 1.38-1.40 V aralığında değişkenlik göstermiştir. Bu çalışmayla birlikte batarya soğutma sistemi tasarımına bir ön hazırlık olarak literatüre katkı sağlanması hedeflenmiştir.

Anahtar Kelimeler: Lityum pil, deşarj oranı, pil modelleme, termal analiz

1. GİRİŞ

Günümüzde motorlu taşıtlar taşımacılıkta hayatımızın kaçınılmaz bir parçası olmuş ve dünya nufüsünun atmasıyla motorlu taşıtlara olan ihtiyaçta giderek artmıştır. Ancak, fosil yakıtla çalışan içtem yanmalı motorların çevreye yaydığı kirli gazlar çevre ve insan sağlığı için büyük tehlike oluşturmaktadır. Bu bağlamda çevreye salınan kirletici gazların içerisinde karbon monoksitin %65'ini, nitrojen oksitin %55'ini ve hidrokabonun %45'ini fosil yakıtlı araçlardan yayılan gazlar oluşturmaktadır [1]. Ayrıca, fosil yakıt kaynaklarınında kısıtlı olması sayısı giderek artan taşıtların talep ettiği enerjiyi karşılamada yetersiz kalmaktadır. Bu problemler karşısında bilim insanlarının yenilenebilir enerjiye olan ilgileri giderek artmış ve bu problemleri hafifletmek, zehili gaz salınımını kontrol altına alabilmek için Elektirkli ve Hibrit Elektrikli araçlar geliştirilmeye başlanmıştır. Bu araçlarda kullanılan kurşun-asit ve nikel-kadmiyum bataryalar, şarj süresinin uzun olması, menzilin düşük olması, batarya fiyatlarının yüksek olması nedeniyle günümüze kadar etkili olamamıştır [2]. Ancak, gelişen teknolojiyle birlikte yüksek enerji yoğunluğu, hızlı şarj ve deşarj, hafiflik, uzun ömür ve çevre dostu olmaları gibi sahip oldukları avantajlarıyla lityum piller, günümüzde enerji depolama uygulamalarına öncülük eden bir teknoloji haline gelmiştir [3]. Lityum pillerin çalışma sıcaklığı -

20ºC ve 60ºC aralığındadır ancak pillerden en yüksek performansı almak için 15ºC ve 35ºC aralığında çalıştırılmaları gerekmektedir [4]. Bu aralığının dışındaki sıcaklık pilde kayda değer bir kapasite kaybına sebeb olmakadır. Ayrıca, batarya modülü içerisinde hücreler arasında ve hücrelerin kendi içerisinde homojen olmayan sıcaklık dağılımıda önemli bir problemdir. Bu nedenle batarya modülü içerisinde üretilen ısının dağıtılması için Batarya Sıcaklık Yönetim Sistemlerinin (BTMS) geliştirilmesi kaçınılmaz bir hal almaktadır. Bunun içinde lityum pil hücrelerinin termal davranışının karakterize edilmesi ve deşarj sırasındaki sergiledikleri termal ve elektriksel performansının bilinmesi gerekmektedir. Bu bağlamda pil modelleme, pil performansına yaklaşımda ve tasarımda önemli bir rol oynamaktadır. Pillerin doğrusal olmayan davranışlarını kontrol edebilmek için güvenilir ve gerçekçi modeller oluşturmak gerekir. Literatürde pil modelleme üzerinde birçok çalışma mevcuttur.

Kök ve Alkaya [5] plaka tipi bir lityum iyon pilin farklı deşarj oranlarında sergilediği termal performansı NTGK modeli kullanarak incelemiştir. Alsharif ve ark. [6] silindirik bir lityum pil hücresinin Eşdeğer Devre Modeli için gerekli parametrelerini Hibrit Darbe Güç Karakterizasyonu (HPPC) yöntemiyle elde ederek 0.5C deşarj oranında pilin termal davranışını incelenmiştir. Alsabari ve ark. [7] İkinci Derece Eşdeğer Devre Modeli kullanarak bir lityum iyon pilin uç gerilimi ve şarj durumu (SOC) açısından elektriksel davranışını Matlab üzerinde simüle etmiştir. Madini ve ark. [8] 13 Ah kapasitede bir lityum titanat oksit pil hücesinin davranışını karakterize etmek için Matlab üzerinde ikinci derece elektriksel eşdeğer devre modeli geliştirmiştir. Yao ve ark. lityum ferro fosfat pil hücresi için Matlab/Simulink'te akım-gerilim performansını tahmin edebilen bir pil modeli geliştirmiştir [9]. Chaoui ve Gualous [10] lityum iyon pilleri için hibrit bir tahmin yöntemi geliştirmiştir. Geliştirilen yöntem, parametrik belirsizliklerin varlığında yüksek tahmin doğruluğu elde etmek için uyarlanabilir kontrol teorisinin ve durum uzayı gözlemcisinin yeteneklerini birleştirmiştir. Liu ve ark. [11] bir pil sisteminde doğru bir şarj durumu (SOC) tahmini için doğrusal olmamayı telafi eden ve daha iyi tahmin doğruluğu sağlayan uyarlanabilir doğrusal olmayan bir gözlemci tasarımı sunmuştur. Gao ve ark. [12] gerçek bir ortamda çalışan $LiFePO_4$ pilin şarj durumunu (SOC) ve sıcaklığını belirlemek için eşdeğer devre ve konvektif termal modeleni birlieştirerek yeni bir birleşik model sunmuştur.

Bu çalışmada Alsharif ve ark. [6] yapmış oldukları çalışma kapsamı genişletilerek silindirik bir lityum pil hücresinin farklı deşarj oranlarında sergilediği termal ve elektriksel davranış nümerik olarak incelenmiştir. Bu bağlamda elde edilen sonuçlarla farklı deşarj oranlarında ihtiyaç duyulacak soğutma siteminin tasarlanmasında literatüre bir katkı sağlanması hedeflenmiştir. Ayrıca, bu çalışmada pilin farklı deşarj oranlarında verebileceği gerilim değerleri tespit edilerek hangi tip uygulamalarda kullanılabileceği üzerine bir fikir ortaya konmuştur.

2. MATERYAL ve YÖNTEM

2.1. Matematiksel Yöntem

Lityum pillerde, anot ve katot, metal folyoların yüzeyine kaplanmış aktif malzemelerden oluşmaktadır. Bu pillerde zıt kutuplu folyolar arasına polimer bir ayırıcı yerleştirilerek elektronların geçişi engellenir. Bir pildeki kimyasal, termal ve elektriksel süreçlerin gelişimini tahmin etmek için Tek Potansiyel Ampirik Pil Modeli ve Çift Potansiyel Çok Ölçekli Çok Alanlı (MSMD) Pil Modeli olmak üzere iki model kullanılmaktadır. Tek Potansiyel Ampirik Pil Modeli, akım toplayıcısı, elektrotlar ve ayırıcının geometrisi tamamen çözüldüğünde kullanışlı bir modeldir. Bu model, tek bir pil hücresinde elektrot ölçeği tahminler için uygundur. Diğer taraftan, özellikle karmaşık geometri sistemlerindeki tüm elektrokimyasal olayları incelemek için sınırlıdır. Hatta tek bir pil hücresi için bile tüm katmanları açıkça çözmek maliyetli olabilmektedir. Ayrıca, birçok endüstriyel uygulama, seri veya paralel bağlanmış bir dizi hücreden oluşan bir batarya modülü kullanmaktadır [5].

MSMD pil modeli, bu sınırlamaları aşmak için çok ölçekli çok boyutlu bir yaklaşıma dayanan homojen bir model kullanmaktadır. Bu yaklaşımda, tüm pil, ortotropik bir sürekli olarak düşünülür ve dolayısıyla ağ, pilin mikroyapısı tarafından artık sınırlanmaz. Bu modelde pil termal ve elektrik alanları, Denklem 1, 2 ve 3'teki diferansiyel denklemler kullanılarak pil hücresi ölçeğinde Hesaplamalı Akışkanlar Dinamiği (HAD) alanında çözülür.

$$\frac{\partial \rho C_p T}{\partial t} - \nabla \cdot (k \nabla T) = \sigma_+ |\nabla \varphi_+|^2 + \sigma_- |\nabla \varphi_-|^2 + \dot{q}_{ECh} + \dot{q}_{short} + \dot{q}_{abuse} \quad (1)$$

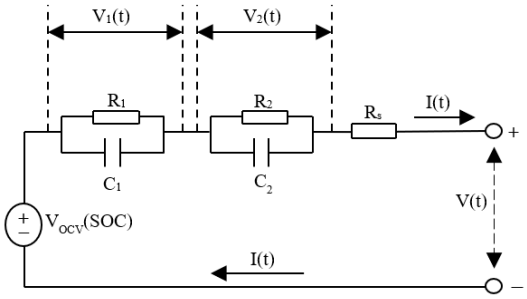
$$\nabla \cdot (\sigma_+ \nabla \varphi_+) = -(j_{ECh} - j_{short}) \quad (2)$$

$$\nabla \cdot (\sigma_{-} \nabla \varphi_{-}) = j_{ECh} - j_{short} \quad (3)$$

Bu denklemlerde σ_{+}ve σ_{-} sırasıyla pozitif ve negatif elektrotlar için etkili elektrik iletkenlikleridir. φ_{+} ve φ_{-} sırasıyla pozitif ve negatif elektrotlar için faz potansiyelleridir. $\dot{j}_{ECh}$ ve $\dot{q}_{ECh}$ sırasıyla hacimsel akım aktarım hızı ve elektrokimyasal reaksiyonlardan kaynaklanan elektrokimyasal reaksiyon ısısıdır. j_{short} ve $\dot{q}_{short}$ sırasıyla pilin dahili kısa devresinden kaynaklanan akım aktarım hızı ve ısı üretim hızıdır. $\dot{q}_{abuse}$, termal olarak kötü çalışma koşulu altında termal kaçak reaksiyonlarından kaynaklanan ısı üretimidir. Bu modelde $\dot{j}_{ECh}$ ve $\dot{q}_{ECh}$ kaynak terimleri bir elektrokimyasal alt model kullanılarak elde edilmektedir. Çeşitli analiz gereksinimlerine uygun olarak MSMD modelde Newman, Tiedemann, Gu ve Kim (NTGK) ampirik modeli, Eşdeğer Devre Modeli (ECM) ve Newman alt Pseudo 2D (P2D) modeli olmak üzere üç elektrokimyasal alt model bulunmaktadır. Bu modeller, farklı düzenlemelere sahip batarya sistemlerinde çeşitli uzunluk ölçeklerine yayılan fiziksel ve elektrokimyasal olayları inceleme esnekliği sunmaktadır [13].

Bu çalışmada yarı ampirik bir model olan Eşdeğer Devre Modeli kullanılmıştır. Bu model, karmaşık bir sistemdeki elemanları basit elektrik devre elemanları ile temsil etmektedir. Eşdeğer Devre Modeli, pilin iç yapısını temsil eden direnç, kapasitans ve indüktans gibi elektrik devre elemanlarını içerir ve her bir eleman, pilin belirli bir özelliğini temsil eder. Eşdeğer Devre Modeli, pilin performansını anlamak, optimize etmek ve kontrol etmek için tasarım sürecinde ve gerçek kullanım sırasında öne çıkan bir modeldir [14].

Bu çalışmada nümerik modelleme Ansys Fluent paket program kullanılarak gerçekleştirilmiştir. Ansys Fluent, Chen'in çalışmalarını takip ederek altı parametreli Eşdeğer Devre Modelini (ECM) benimsemiştir. Üç direnç ve iki kapasitörden oluşan bu devre modeli Şekil 1'de gösterilmiştir. Devredeki gerilim kaynağı, hücre yüksüz ve tam dengede olduğunda batarya terminallerinden geçen gerilimi tanımlayan açık devre gerilimini (V_{OCV}) temsil eder. Seri bağlı direnç (R_s), pilin ısı enerjisi olarak harcadığı gücü açıklayan Ohmik dirençtir [15]. İki direnç-kapasitör alt devreleri (R_1, C_1, R_2 ve C_2), pilin difüzyon dinamiklerini açıklayan devredeki zaman sabitlerini temsil etmektedir. V(t), pilin kayıplarını elde etmek için açık devre geriliminden çıkarılan devrenin pasif bileşenleri boyunca ölçülen gerilim düşüşüdür. I(t), devrenin girişi olan ve deneysel olarak elde edilen akım ölçümleridir [6].



Şekil 1. Eşdeğer devre modeli

Şekilde gerilim-akım ilişkisi aşağıdaki elektrik devre denklemlerinin çözülmesiyle elde edilmektedir.

$$V(t) = V_{OCV}(SOC) - V_1 - V_2 - R_s(SOC)I(t) \quad (4)$$

$$\frac{dV_1}{dt} = -\frac{1}{R_1(SOC)C_1(SOC)}V_1 - \frac{1}{C_1(SOC)}I(t) \quad (5)$$

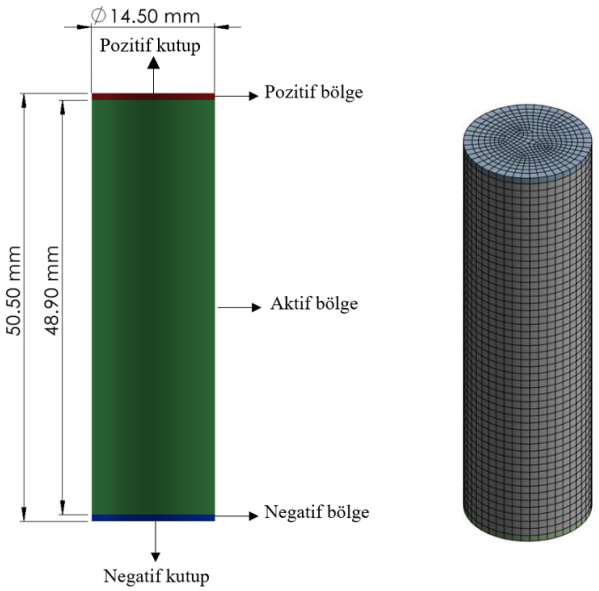
$$\frac{dV_2}{dt} = -\frac{1}{R_2(SOC)C_2(SOC)}V_2 - \frac{1}{C_2(SOC)}I(t) \quad (6)$$

$$\frac{d(SOC)}{dt} = \frac{I(t)}{3600Q_{ref}} \quad (7)$$

Denklem 4'te gösterilen çıkış gerilimi V(t), Şekil 1'de verilen devre için çevre denkelemlerinin çözümünden hesaplanabilen pil hücresi gerilimidir. Belirli bir pil için açık devre gerilimi, rezistör dirençlerinin, kapasitör kapasitanslarının, pilin şarj durumunun (SOC) ve sıcaklığın fonksiyonlarıdır. Bu fonksiyonlar Ansys Fluent'te iki boyutlu tablo, polinom ve Chen'in sunduğu biçim olmak üzere üç farklı şekilde ifade edilebilmektedir. Diğer iki yöntemden farklı olarak tablo yönteminde polinom ve Chen biçiminde dikkate alınmayan sıcaklık etkisi hesaplamaya dahil edilebilmektedir. Ancak, Alsharif ve ark.'larının [6] çalışmasında sıcaklık sabit tutulduğu için bu çalışmada da sabit olarak benimsenmiştir. Bu bağlamda bu çalışmada tablo yöntemi benimsenmiş ve ECM parametrelerinin sabit sıcaklıkta SOC değerine bağlı değişimi literatürdeki Alsharif ve ark.'larının [6] çalışmasından bir boyutlu tablo olarak alınmıştır.

2.2. Sınır Şartları ve Geometri

Ele alınan çalışma kapsamında silindirik bir lityum pilinin farklı deşarj oranlarında sergilemiş olduğu termal ve elektriksel davranış nümerik olarak incelenmiştir. Bu bağlamada modelleme Ansys Fluent paket programı içerisinde MSMD batarya modeli kullanılarak gerçekleştirilmiştir. Elektrokimya modeli olarak Eşdeğer Devre Modeli (ECM) benimsenmiştir. Pilin nominal kapasitesi 3000 mAh, minimum durma gerilimi 0.8 V ve maksimum durma gerilimi 1.5 V olarak girilmiştir. ECM parametreleri Alsharif ve ark.'larının [6] çalışmasından bir boyutlu tablo olarak alınmış ve programa girilmiştir. Bu şartlar altında pil 0.25C, 0.50C, 0.75C ve 1C oranlarında deşarj edilmiştir. Pilin ürettiği ısıyı transfer edebilmesi için pil yüzeylerinde konveksiyon sınır koşulu tanımlanmıştır. Bu yüzeylerde taşınım katsayısı 28 W/m^2K girilmiştir. Hesaplamalar üç boyutlu ve zamana bağlı koşullar altında gerçekleştirilmiş ve zaman adımı 30 s olarak ayarlanmıştır. Modellenen pile ait geometri ve ağ yapısı Şekil 2'de verilmiştir. Pil geometrisi pozitif, negatif ve aktif olmak üzere üç bölgeden ve iki uç kısmında bulunan pozitif ve negatif kutuplardan oluşmaktadır. Hesaplamaların gerçekleştirilebilmesi için geometrinin uygun bir ağ yapısıyla örülmesi gerekmektedir. Bu bağlamda 1 mm ağ boyutu ve hexahedral ağ tipi kullanılarak toplamda 21736 eleman ve 23373 nokta içeren bir ağ yapısı oluşturulmuştur.



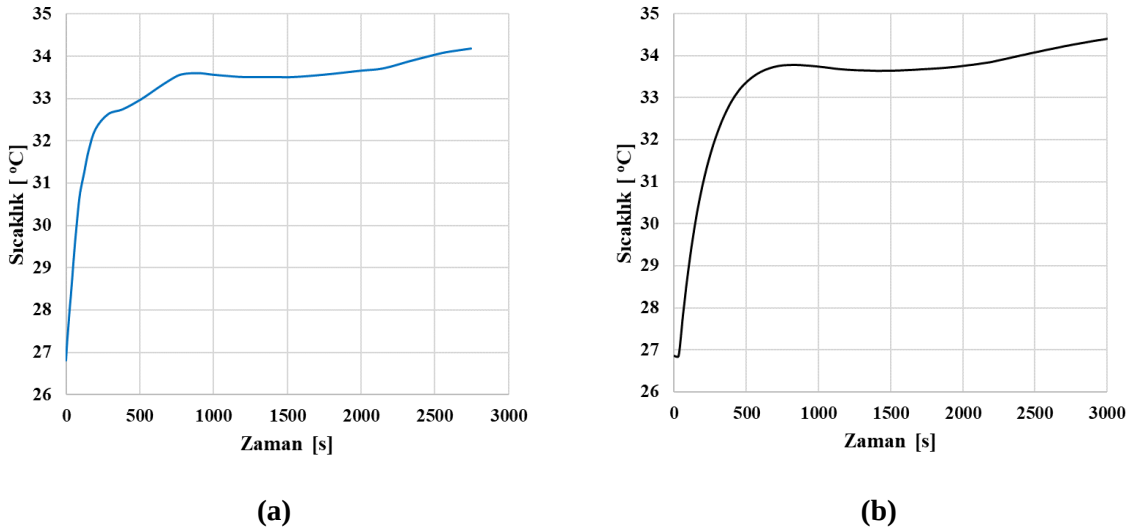
(a) **(b)**

Şekil 2. Pile ait **(a)** geometri ve **(b)** ağ yapısı

3. BULGULAR ve TARTIŞMA

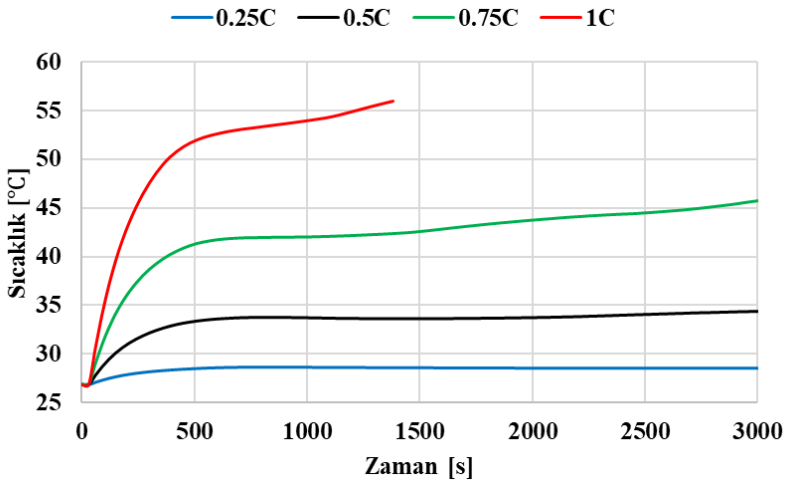
Çalışma kapsamında silindirik bir lityum pilin 0.25C, 0.5C, 0.75C ve 1C olmak üzere farklı deşarj oranlarında sergilediği termal ve elektriksel performans nümerik olarak incelenmiştir. Çalışmada kullanılan pile ait

özellikler ve ECM model parametreleri Alsharif ve ark.'larının [6] çalışmasından alınmış olup model doğrulaması pilin zamana bağlı sıcaklık değişimleri karşılaştırılarak gerçekleştirilmiştir. Bu bağlamda 0.5C deşarj oranında lityum pilin zamana bağlı sıcaklık değişiminin literatür ile karşılaştırması Şekil 3'de verilmiştir. Şekil incelendiğinde sıcaklık trendinin iyi bir uyum içinde olduğu görülmüştür. Model doğrulaması sonrasında farklı deşarj oranları için lityum pilin termal ve elektriksel hesaplamaları gerçekleştirilmiştir. Elde edilen sonuçlar zamana bağlı gerilim ve sıcaklık değişimi grafikleri ve pil üzerinde meydana gelen sıcaklık dağılımları cinsinden verilmiştir.



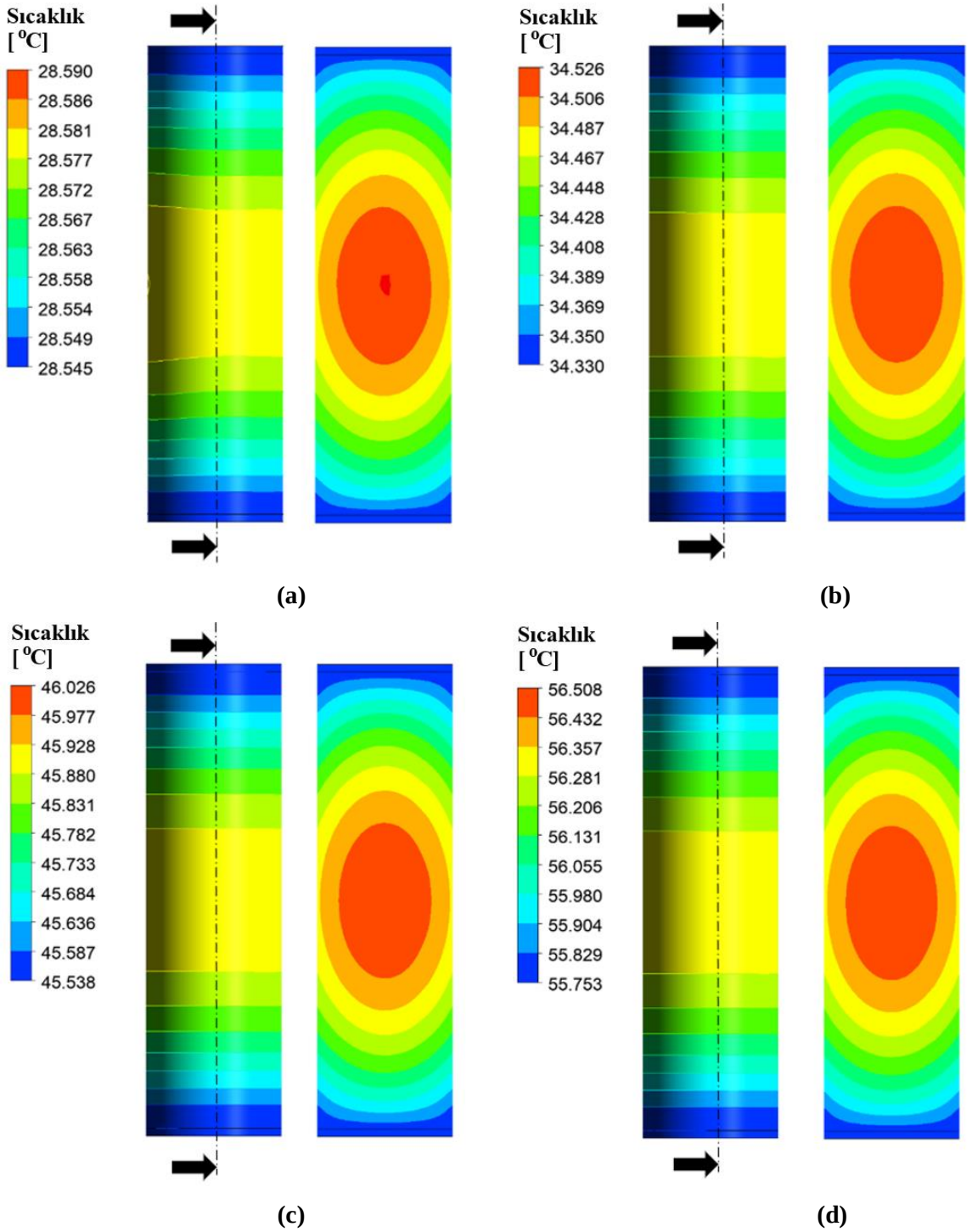
Şekil 3. 0.5C deşarj oranında lityum pilin zamana bağlı sıcaklık değişiminin literatür ile karşılaştırması. **(a)** literatür ve **(b)** sunulan çalışma

Farklı deşarj oranlarında pil yüzeyinde meydana gelen ortalama sıcaklıkların zamana bağlı değişimi Şekil 4'de verilmiştir. Pil deşarj oranının artmasıyla birlikte pil yüzeyinde meydana gelen sıcaklıklar yükselmiştir. Bu bağlamda en düşük pil sıcaklığı 0.25C deşarj oranın'da, en yüksek pil sıcaklığı ise 1C deşarj oranında elde edilmiştir. En yüksek pil sıcaklıkları sırasıyla 1C'de 56.0°C, 0.75C'de 45.7°C, 0.5C'de 34.4°C, 0.25C'de 28.7°C'ye ulaşmıştır. 1C durumunda pilin daha hızlı deşarj olmasıyla yaklaşık 1400 s sonra pil gerilimi durma gerilimine düşmüş ve deşarj süreci sonlanmıştır. 0.25C ve 0.5C deşarj oranlarında yaklaşık 500 s sonrasında pil sıcaklıkları kararlı bir duruma gelirken, 0.75C ve 1C deşarj oranlarında pil sıcaklıkları artmaya devam etmiştir.



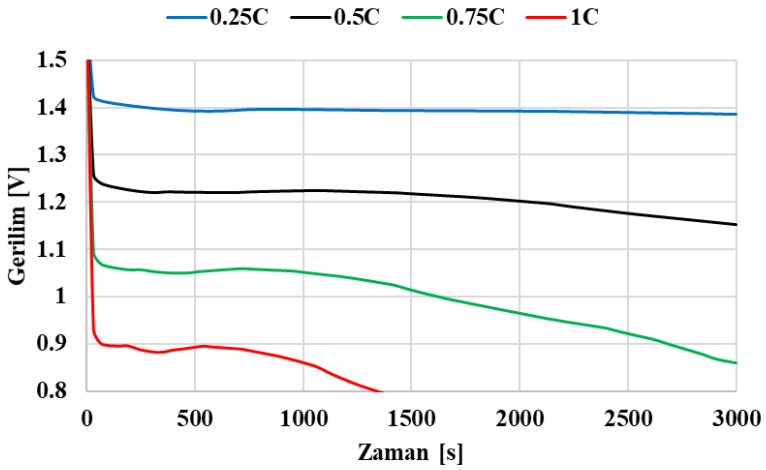
Şekil 4. Farklı deşarj oranlarında pil yüzeyinde meydana gelen ortalama sıcaklıkların zamana bağlı değişimi

Farklı deşarj oranlarında pil yüzeyinde ve merkezinde meydana gelen sıcaklık dağılımları Şekil 5'de verilmiştir. Deşarj oranının artmasıyla pillerdeki çekirdek sıcaklıklarıda yükselmiştir. Bu bağlamda yüzey sıcaklıklarında olduğu gibi en yüksek çekirdek sıcaklıkları sırasıyla 1C'de 56.5ºC, 0.75C'de 46.0ºC, 0.5C'de 34.5ºC ve 0.25C'de 28.6ºC olarak meydana gelmiştir. Sıcaklık dağılımı tüm pillerde merkezden dış yüzeylere doğru azalarak gerçekleşmiştir. Aktif bir soğutma sisteminin olmaması nedeniyle tüm pillerde çekirdek ve pil yüzeyi arasındaki sıcaklık farkı oldukça düşük kalmıştır. Her ne kadar çekirdek ve yüzeydeki sıcaklık farkları küçük olsa da deşarj oranının artmasıyla birlikte bu sıcaklık farklarıda artmıştır.



Şekil 5. Farklı deşarj oranlarında pil yüzeyinde ve merkezinde meydana gelen sıcaklık dağılımları. **(a)** 0.25C, **(b)** 0.5C, **(c)** 0.75C ve **(d)** 1C

Farklı deşarj oranlarında pil hücresi geriliminin zamana bağlı değişimi Şekil 6'da verilmiştir. Pile yük bindirildiğinde gerilim değerleri ani bir düşüş göstermiş ve sonrasında azalan bir formda gerilim düşmeye devam etmiştir. Deşarj oranı yükseldikçe ani düşüş değeride artmıştır. 1C deşarj oranında pil gerilimi yaklaşık 1400 s sonra 0.8 V değerine düşmüş ve minimum durma koşulu sağlandığı için similasyon bu sürede sonlanmıştır. Diğer taraftan deşarj oranı arttıkça pil hücresi gerilimi azalmış ve stabil olarak verebilikleri gerilim süreleride kısalmıştır. Bu bağlamda 0.25C deşarj oranında pil hücresi gerilimi başta 1.40 V seviyelerindeyken zamanla 1.38 V seviyesine düşmüş ve nispeten stabil bir gerilim değeri vermiştir. 0.5C deşarj oranında yaklaşık 2000 s boyunca pil hücresi gerilimi 1.22 V civarında stabil kalmış ve daha sonrasında 1.15 V seviyesine kadar düşmüştür. 0.75 C deşarj oranında pil hücresi gerilimi yaklaşık 1000 s boyunca 1.05 V civarında stabil kalmış ve sonrasında hızlı bir düşüşle birlikte 0.86 V seviyesine gelmiştir. 1C deşarj oranında ise yaklaşık 660 s boyunca pil hücresi gerilimi 0.9 V civarında stabil kaldıktan sonra hızla 0.8 V seviyesine düşmüştür.



Şekil 6. Farklı deşarj oranlarında pil hücresi geriliminin zamana bağlı değişimi

4. SONUÇLAR

Çalışma kapsamında silindirik bir lityum pil hücresinin farklı deşarj oranlarında sergilediği termal ve elektriksel performans nümerik olarak incelenmiştir. Nümerik azalizler Ansys fluent paket programında, üç boyutlu ve zamana bağlı şartlarda gerçekleştirilmiştir. Pil karakterizasyonu Eşdeğer Devre Modeli kullanılarak modellenmiş olup model parametreleri Alsharif ve ark. [6] çalışmasından alınmıştır. Sonuçlar pil hücesinin gerilim ve sıcaklık değerlerinin zamana bağlı değişimi ve hücre üzerindeki sıcaklık dağılımı açısından değerlendirilmiştir.

Çalışma sonucunda aşağıdaki sonuçlar elde edilmiştir:

- Deşarj oranı arttıkça pil hücresinin sıcaklığı artmış, gerilim değeri azalmıştır.
- En yüksek hücre sıcaklığına 1C deşarj oranında, en düşük ise 0.25C deşarj oranında ulaşılmıştır.
- 1C deşarj oranında pil hücresinin yüzeyinde ortalama sıcaklık 56.0ºC'ye, 0.25C'de ise 28.7ºC'ye ulaşmıştır.
- En yüksek hücre gerilimi 0.25C deşarj oranında, en düşük ise 1C deşarj oranında elde edilmiştir.
- İncelenen zaman aralığında 0.25C ve 0.5C deşarj oranlarında pil sıcaklıkları belli bir süreden sonra sabit kalırken, 075C ve 1 C'de pil hücresi sıcaklığı artmaya devam etmiştir.
- Pil hücresi gerilimi 1C deşarj oranında 0.8-0.9 V ve 0.25C'de ise 1.38-1.40 V aralığında değişkenlik göstermiştir.
- 1C deşarj oranında pil hücresi yaklaşık 1400 s sonra durma gerilimine denk gelmiştir.
- Deşarj oranının artmasıyla başlangıçtaki ani gerilim düşüşleride artmış ve pilin stabil olarak sağladığı gerilim süresi azalmıştır.

- Her ne kadar deşarj oranı attıkça pil hücresinin çekirdek sıcaklığı ve yüzey sıcaklığı arasındaki fark artsada, aktif bir soğutma sisteminin kullanılmaması nedeniyle bu fark tüm durumlarda çok küçük kalmıştır.

Gelecekte, bu çalışmada kullanılan pil modelleme yöntemi kullanılarak daha büyük batarya sistemleri için soğutma sistemi tasarımları çalışılabilir.

TEŞEKKÜR

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DAĞITIK ÜRETİM TESİSLERİNİN DAĞITIM ŞEBEKELERİNE ETKİLERİNİN DEĞERLENDİRİLMESİ

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ÖZET

Dağıtık üretim tesisleri, T.C. Enerji ve Tabii Kaynaklar Bakanlığı'nın Türkiye Elektrik Dağıtım A.Ş. 'ne ait elektrik dağıtım şebekelerine bağlanması üzere bağlantı görüşü verilmiş ve belirli mevzuatlar gereğince dağıtım şebekelerine lisanslı/lisanssız kapsamda bağlanmış olan tesislerdir. Bu üretim tesisleri genellikle güneş, rüzgâr ve hidrolik vs. gibi yenilenebilir enerji kaynaklarından enerji üretimi yapar. Söz konusu tesislerin bazıları, tesis sahiplerinin tüketim noktalarında kurulmuş ve tüketim noktalarındaki sayaçlarıyla doğrudan irtibatlandırılmış olup, tüketim yerinde üretimin anlık olarak harcanması üzere planlanmıştır. Diğer üretim tesisleri de kaynakların coğrafi açıdan bulunduğu yerlerde değerlendirilmiş ve dağıtım şebekeleri üzerinden üretimin enterkonnekte şebekeye kazandırılması amacıyla planlanmıştır. Üretilen enerjinin dağıtım şebekelerine ait enerji nakil hatlarıyla bu şebekede tüketime harcanması veya enterkonnekte şebekede, yine dağıtım şebekelerine ait enerji nakil hatları üzerinden ihtiyaç duyulan noktalara iletilerek tüketilmesi üzere planlama çalışır durumdayken, nominal şebeke koşulları ve arıza durumları için etkilerinin incelenmesi ve teknik kalite değerlerinin hangi açıdan etkilendiğinin değerlendirilmesi büyük önem arz etmektedir. Elektrik Dağıtım Sisteminin Teknik Kalitesi, kullanıcıların elektrik enerjisi talebinin; gerilimin frekansı, genliği, dalga şekli ve üç faz simetrisi açısından ulusal ve uluslararası standartlar ile ilgili mevzuatlarda belirlenen değişim sınırları içerisinde kesintisiz karşılanabilme kavramıdır. Günümüz şartlarında sayıları ve kurulu güçleri sürekli artan dağıtık üretim tesislerinin, dağıtım şebekelerindeki bağlantı süreçleri ve sonrasında işletme koşulları incelendiğinde enerjideki teknik kalite hem dağıtım şebekesi sistemlerini hem de kullanıcıları birçok yönden etkilemektedir. Dağıtım şebekelerinin, birinci derecede kaynağı olan Türkiye Elektrik İletim AŞ'nin güç trafolarından sonra, dağıtım şebekelerine doğrudan bağlı üretim tesisleri de ikinci sırada olup önemli kaynaklar arasındadır. Bu kaynaklardaki güç kalitesi, verimi, özellikle gerilim, frekans ve hat kayıpları konusunda önemli bir yere sahiptir. Bu noktada dağıtım şebekelerindeki dağınık üretim bölgeleri, TEİAŞ kaynaklarının uzağında bulunan bölgeler için teknik kalitede düzenleyici bir görev üstlenmiş durumdadır. Dağıtık Üretim Tesislerinin bağlantı noktalarındaki hat uzunlukları, bağlantı güçleri ve bağlandıkları enerji nakil hatlarındaki kesitleri, üretim ve tüketim yönünden teknik açıdan analizlerinin çok hassas bir şekilde hesaplanmalıdır. Analizi verimli olmayan üretim santrelleri, gerilim yükselmesi, kesit uyuşmazlığı ve kısa devre akım-gerilim-güç değerlerini olumsuz yönde etkilemektedir. Bu bağlamda dağıtık üretim tesislerinin, dağıtım şebekelerine bağlanmasında hem dağıtım sistemi hem de ihtiyaç duyulan üretim sistemi açısından dağıtım şebekesinin durumu ve üretim tesisinin teknik kaliteyi etkileyecek tüm parametreleri ile analiz etmek gerekmektedir.

Dağıtık üretim tesislerinin dağıtım şebekesine bağlanmasında, şebekedeki enerjinin teknik kalitesinin mevzuatlar kapsamındaki uygunluğunun sağlanabilmesi açısından aşağıdaki teknik analizlerinin sonuçlarının uygun olması önemlidir.

Anahtar Kelimeler: Dağıtık üretim tesisleri, dağıtım şebekesi, teknik kalite.

Giriş

Dağıtık Üretim

Dağıtık ya da Dağıtılmış üretim (DÜ), düşük ya da orta gerilim seviyesinde (0,4-36kV) yapılan elektrik enerjisi üretimi ve enerji depolamadır. DÜ, tüketici merkezlerine yakın elektrik dağıtım şebekesine bağlı ya da tek

başına çalışabilen, coğrafi olarak yayılı kaynakları içerir. Küçük güçlü santrallerin yanında, rüzgâr, güneş gibi yenilenebilir enerji kaynakları, yakıt pili ve enerji depolama birimleri dağıtılmış üretim kaynaklarıdır (Arsoy, Perdahçı, 2010).

Dağıtık Üretim Tesisleri

Dağıtık üretim tesisleri, T.C. Enerji ve Tabii Kaynaklar Bakanlığı'nın Türkiye Elektrik Dağıtım A.Ş. 'ne ait elektrik dağıtım şebekelerine bağlanması üzere bağlantı görüşü verilmiş ve belirli mevzuatlar gereğince dağıtım şebekelerine lisanslı/lisanssız kapsamda bağlanmış olan tesislerdir. Bu üretim tesisleri genellikle güneş, rüzgâr ve hidrolik vs. gibi yenilenebilir enerji kaynaklarından enerji üretimi yapar.

Söz konusu dağıtık üretim tesisleri;

1- Tesis sahiplerinin tüketim noktalarında kurulmuş ve tüketim noktalarındaki sayaçlarıyla doğrudan irtibatlandırılmış olup, tüketim yerinde üretimin anlık olarak harcanması üzere planlanmıştır.

2- Diğer üretim tesisleri de kaynakların coğrafi açıdan bulunduğu yerlerde değerlendirilmiş ve dağıtım şebekeleri üzerinden üretimin enterkonnekte şebekeye kazandırılması amacıyla planlanmıştır.

Dağıtık Üretim Tesisleri Bağlantı Tipleri

Dağıtık üretim tesislerinin sisteme bağlantı tipleri 5 farklı tipte değerlendirilmiştir.

Sisteme Bağlantı Noktaları;

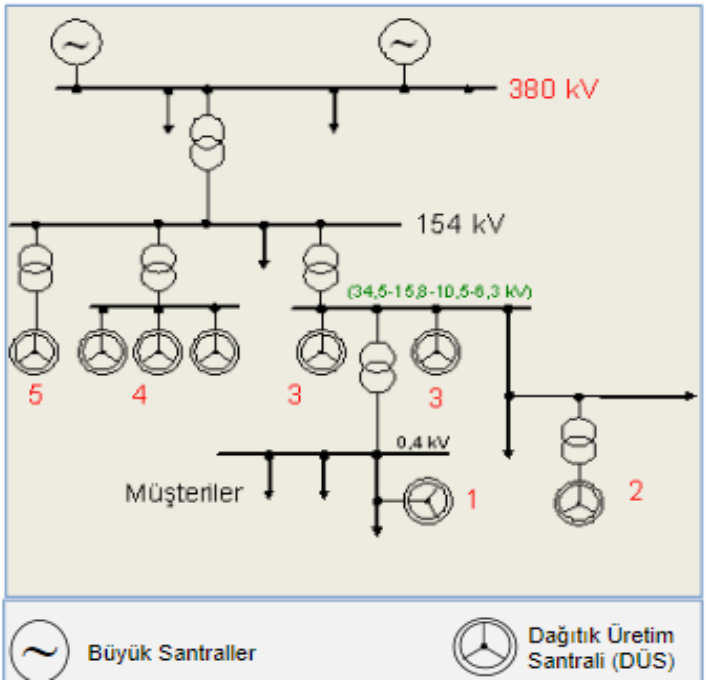
1- AG' de Bağlantı-Lisanssız Üretim

2- Gerilim düşümü ve güç kaybı hesaplarına göre hattın kapasitesine bağlı olarak YG Dağıtım Şebekesi' ne bağlı santraller-Lisanslı/Lisanssız Üretim

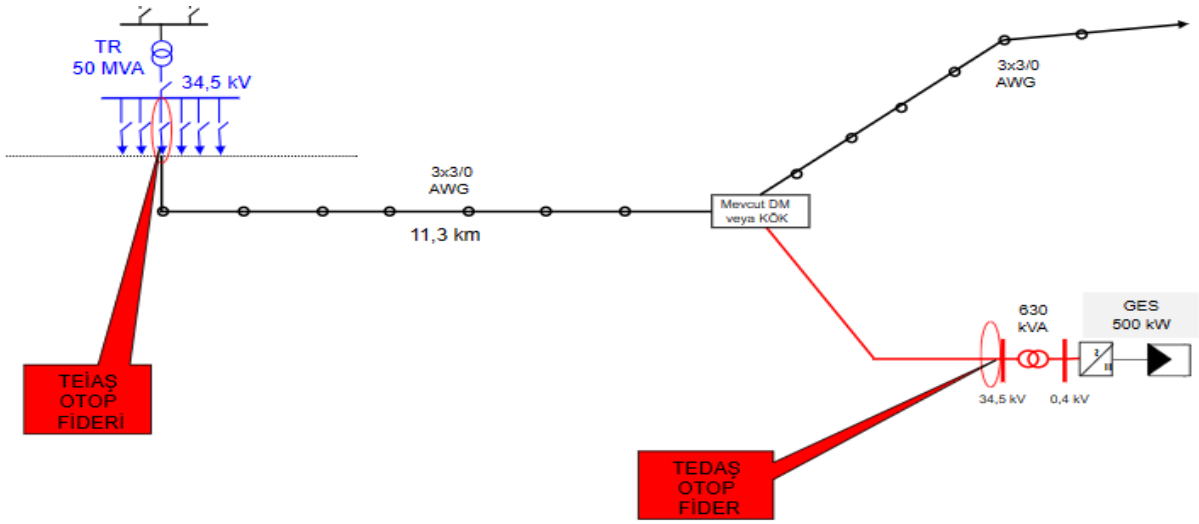
3- Genelde kurulu gücü 10 MW ile 50 MW arasında olan üretim tesislerinin, müstakil hat ve fiderlerle TM'lere direkt bağlı santraller

4- Rüzgâr Çiftliği, Güneş Tarlaları vb. YEKA büyük ölçekli santrallerin TEİAŞ'ın 154 kV TM baralarına bağlı santraller

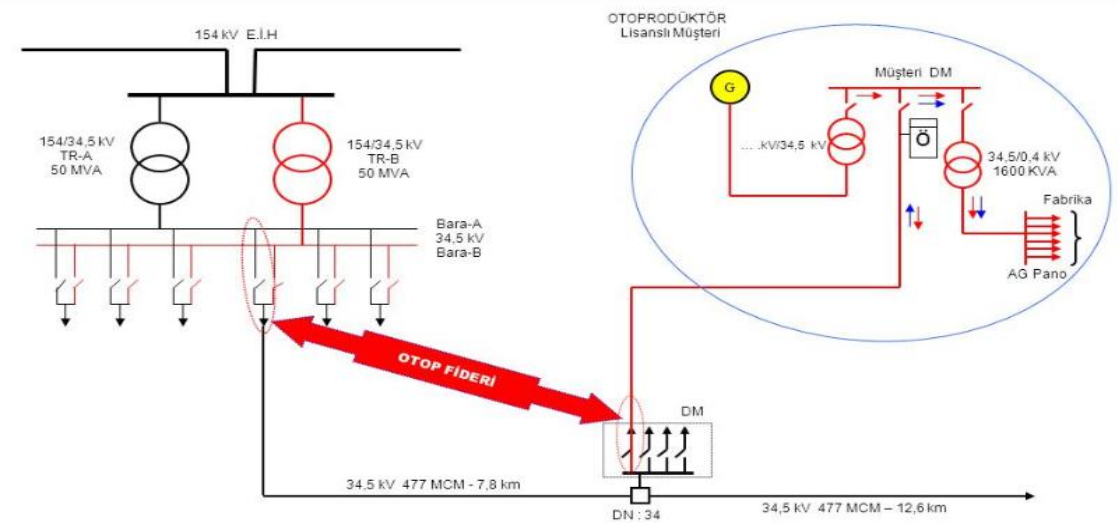
5- Kurulu gücü 50 MW'ın üzerinde olan üretim tesisleri, TEİAŞ'a direkt bağlı santraller.



Şekil 1. Dağıtık Üretim Tesis Örnekleri (Şimşek, 2011)



Şekil 2. Gerilim düşümü ve güç kaybı hesaplarına göre hattın kapasitesine bağlı olarak YG Dağıtım Şebekesi' ne bağlı santraller-Lisanslı/Lisanssız Üretim (Şimşek, 2011)



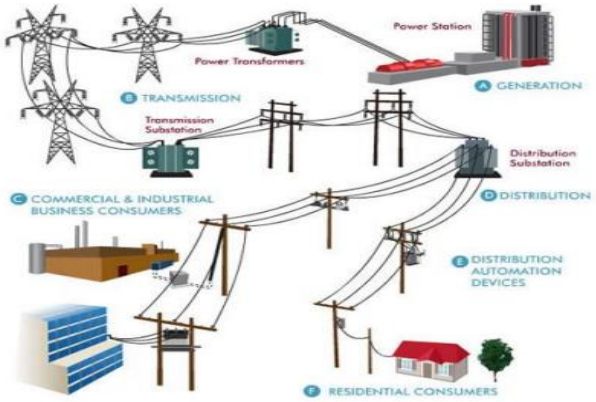
Şekil 3. Müşterinin kendi tüketim tesisindeki üretim santralinin bağlantısı (Şimşek, 2011)

Dağıtık Üretim Tesislerinin Dağıtım Şebekelerine Olan Etkileri

1-Dağıtık Üretim Tesislerinin Dağıtım Şebekesinin Yük Akışına/Akış Yönüne Olan Etkileri

Elektrik dağıtım şirketlerinin mevcut şebekelerinin en önemli enerji kaynağı, TEİAŞ' ın bölgeleri enerji sağladı 154 kV veya 380 kV Trafo merkezlerindeki 154/31,5 kV güç trafolarıdır. Bu trafolar birinci derecede kaynak pozisyonundadır. Dağıtım şebekelerindeki referans gerilim, frekans ve tüm teknik vs. değerler, TM'lerdeki bu trafolardan bölgelere sağlanan enerjideki değerlerdir.

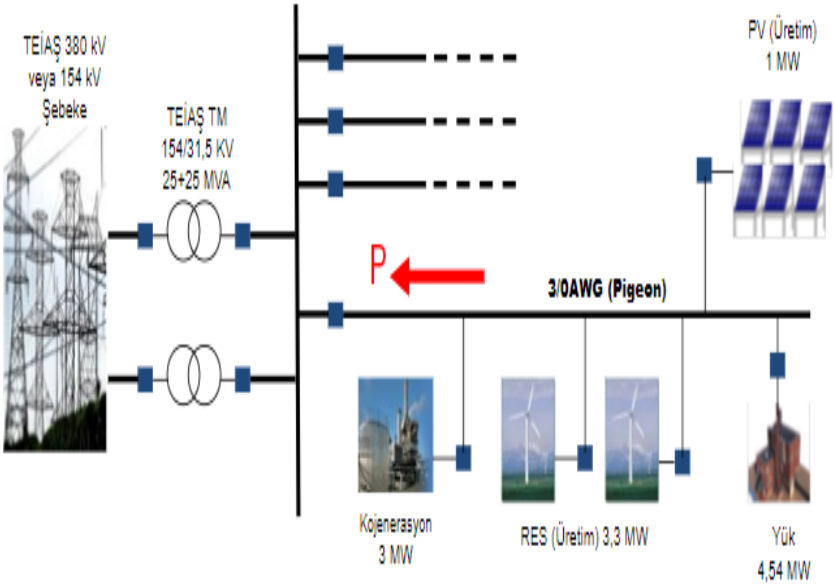
Dağıtım şebekelerine, herhangi bir enerji üretim tesisi bağlanmamışsa, şebekedeki yük akış yönü iletim sisteminden dağıtım sistemindeki tüketicilere doğrudur. Yani dağıtım ağlarında enerji akışı, tek yönlü olarak yüksek gerilim iletim sisteminden son kullanıcın bağlı olduğu pasif dağıtım sistemine doğrudur (Akdeniz, 2006).



Şekil 4. Tek Yönlü Yük Akış Yönlü Dağıtım Şebekesi Örneği (Anonim, 2023)

Dağıtım hatlarına bağlı üretim santrallerinin olduğu dağıtım şebekelerinde, konumuzun içeriğindeki dağıtık üretim tesislerinin olduğu noktaları dikkate alarak yük akış yönü ise iki durumda incelenir;

1. 1-Tüketicilerin enerji sarfiyatı, üretilen enerji miktarından fazla ise akış tüketim noktalarına doğrudur. İletim sisteminden dağıtıma gelen enerjiyi ve üreticinin şebekeye vermiş olduğu enerji tüketici tesislerinde harcanır.
2. 2-Tüketicilerin enerji sarfiyatı, üretilen enerji miktarına az ise akış yönü iletim sistemine doğrudur. Burada dağıtım şebekesindeki enerji üretim santrallerinin üretiminin tüketicilerin kullanımından sonraki fazlası TEİAŞ' ın güç trafosuna doğru iletimi söz konusudur.



Şekil 5. Dağıtım şebekesinden iletim sistemine olan akış yönü (Şimşek, 2011)

Genellikle, normal işletme koşullarında tüketicilere yakın noktalarda şebekeye bağlantı yapan küçük güçlü DEÜ kaynakları iletimden kaynaklan kayıpları düşürmekte ve dolayısıyla besleme hatlarının ucunda oluşan gerilim düşümlerini de azaltmaktadırlar. Bu tip şebekelerdeki dağıtık üretim santralleri, enerji kalitesinin iyileştirilmesine katkıda bulunur (Akdeniz vd, 2006).

Dağıtım şebekesinde, tüketim noktalarına uzak noktalarda tesis edilmiş üretim santralleri, güç ve teknik kalitede gelelim yükselmesi/çökmesi ve enerji nakil hatlarında aşırı yüklenme gibi istenmeyen etkilere sebep olabilirler. Yük akış yönü, bağlanacak santrallerin kurulu gücü ve bağlantı yapılacak baranın kaynak tarafındaki kısa devre gücü ile iletken kesitlerinin uygunluğu, gerilim değerlerinin yükselmesi veya düşmesi ile doğrudan bağlantılıdır. Aynı zamanda kayıplar üzerinde de etkisi büyüktür.

Ani gelişen olaylar sonucunda, şebekeye ani yüklerin girişi ve çıkışı yük akış yönünün değişimine yol açıp, yine gerilim düşümü veya yükselmesi gibi sonuçlara yol açabilir. Yük akış yönü değişimi ile, gerilimdeki nominal durumun değişmesi reaktif güç kalitesini ve kayıpları da doğrudan etkiler.

2-Kısa Devre Analizi

Bir elektrik şebekesinde verilen bir noktanın kısa devre gücü şebekenin o noktadaki performansının bir ölçüsünü gösterir. Kısa devre gücünün aynı zamanda gerilim kalitesi üzerinde de etkisi söz konusudur. Eğer zayıf şebekede (kısa devre gücü küçük) empedans büyük ise gerilim dalgalanmaları büyük olur. Güçlü bir Şebekede (kısa devre gücü büyük) empedans küçük ise gerilim dalgalanmaları da küçük olur. Eklenen kaynaklar şebekenin kısa devre gücünü arttıracağından, güç kalitesini de iyileştirici yönde rol oynarlar. Bunun yanında zayıf bir şebekeye bağlanacak büyük güçlü bir kaynak güç kalitesi problemlerine yol açabilir (Oliva, 2003)

Kısa devre konusu hem dağıtım şebekesinin hem de iletim şebekesinin bütün unsurlarını doğrudan etkileyen önemli bir konudur. En başta iletim şebekesinden itibaren düşünürsek, özellikle 154/31,5 kV güç trafosunun ve 31,5 kV barasında kısa devre akım ve gerilim hesapları, bağlantı yapacak dağıtım barasındaki üretim tesisinin faz-faz, faz-toprak ve vs. gibi tüm alternanslardaki arıza anında gerçekleşmesi muhtemel kısa devre akım ve gerilim hesapları, şebekeye eklenecek unsurların kısa devre hesapları ile uyumlu olmalıdır. Hesapları uygun değerlerde olmayan tesislerin arıza anında dağıtım şebekesindeki enerji nakil hatları, kesici, ayırıcı vs. şalt ekipmanlarına vereceği hasarların yanında trafo merkezindeki güç trafosu ve iletim baralarına olan hasarları da gerek ekonomik gerekse hizmet kalitesi (uzun-kısa kesinti sayı ve süreleri) ve enerji rejimini de olumsuz etkiler. Bu hususta sekonder koruma sistemlerinin kısa devre hesapları altında optimum bir koordinasyon düzeninde ayarlanarak iletim ve dağıtım ekipmanlarını korumalıdır.

3-Güç Kalitesine Etkisi

Standartlara göre, elektrik üreticisi sağladığı gerilimin kalitesinden sorumlu iken tüketici de sistem kapasitesine bağlı olarak neden olduğu harmonik seviyesinden sorumludur. Dolayısıyla, sisteme bağlantıda güç elektroniği tabanlı arayüzlere ihtiyaç duyan mikro türbinler, yakıt pilleri ve fotovoltaikler gibi dağıtılmış üretim kaynakları da harmonik kaynakları olarak düşünüldüklerinden sınırlı kapasite ile kullanılmaları gerekmektedir. Ancak, küçük güçlü dağıtılmış üretim birimlerinin harmonik enjeksiyonunun ekonomik nedenlerden dolayı daha fazla olacağı unutulmamalıdır (Sarıkaya ve Yumurtacı. 2011).

Harmonik: Doğrusal olmayan yükler veya gerilim dalga şekli ideal olmayan jeneratörlerden dolayı bozulmaya uğramış bir alternatif akım veya gerilimde, ana bileşen frekansının tam katları frekanslarda oluşan sinüsoidal bileşenlerin her birini,

Fliker: Yükteki dalgalanmalar nedeniyle ortaya çıkan ve aydınlatma armatürlerinde kırpışmaya yol açan 50 Hz altındaki gerilim salınımlarını, (12 Eylül 2006, Sayı : 26287 Resmî Gazete)

Dağıtım şebekesinde kurulan santrallerin bir çoğunda istenmeyen harmonik ve flickerlardan üreten ekipmanlar bulunmaktadır.

Elektrik Piyasasında Dağıtım Sisteminde Sunulan Elektrik Enerjisinin Tedarik Sürekliliği, Ticari Ve Teknik Kalitesi Hakkında Yönetmelik'e göre;

Dağıtım sistemi kullanıcıları IEEE Std.519-1992 standardında ya da bunun revizyonlarında belirtilen aşağıdaki harmonik sınır değerlerine uymakla yükümlüdür.

Dağıtım şirketi, fliker etkisi için kullanıcının IEEE Std.1453-2004 standardına ya da bunun revizyonlarında belirtilen aşağıdaki sınır değerlere uymasını sağlar.

4-Sistem Güvenilirliğine Etkisi

Sistem güvenilirliği, enerjinin kullanıcılara dağıtımı yapılırken sistemin sağlamlık göstergesi ve başarı oranıdır. Yeterlilik ve güvenlik ölçütleri ile değerlendirilir.

- Yeterlilik: Yeterli bir memnuniyette enerji talebini karşılayabilme,
- Güvenlik: Ansızın gerçekleşen arıza karşı varlığını sürdürebilme.

Kısa devre, kapasite yetersizliği, akış yönü ve koruma sistemleri sistem güvenilirliğini doğrudan etkiler ve bu husustaki değişikliklerden de doğrudan etkilenir (Gözel, 2009).

5-Koruma Sistemlerine Olan Etkileri

Güç sistemlerinin korunmasında hedeflenen güç sisteminin emniyetli bir şekilde çalışmasının sağlanmasıdır. Ayrıca, koruma koordinasyonu ile arıza durumlarının sisteme etkilerinin minimum seviyede tutulması sağlanmaktadır. Tek yönlü enerji akışına göre tasarlanan dağıtım sistemleri, enerji üretiminin entegrasyonu ile çift yönlü değişken güç akışı istemlerine dönüşebilir. Enerji üretim tesislerinin entegrasyonu, bağlandığı bölgeye göre güç akışlarını değiştirebilecek nitelikte olabilmektedir. Güç akışı değiştiğinde de hem reaktif güç kontrol yapısı farklılaşır hem de dağıtım sistemine ait koruma koordinasyonu değişir (Mao, 2003)

Çift yönlü sistemde koruma, her iki akış yönüne göre koordinasyonu farklı olur. EDAŞ Sistem kullanıcısı olarak buna dikkat etmelidir. Özellikle adalaşmanın söz konusu olduğu durumlarda işletme toprağını da devre dışı bırakacağından dolayı önemli seviyelerde gerilim yükselmelerine neden olabilir.

6-Sistem Güvenilirliğine Etkisi

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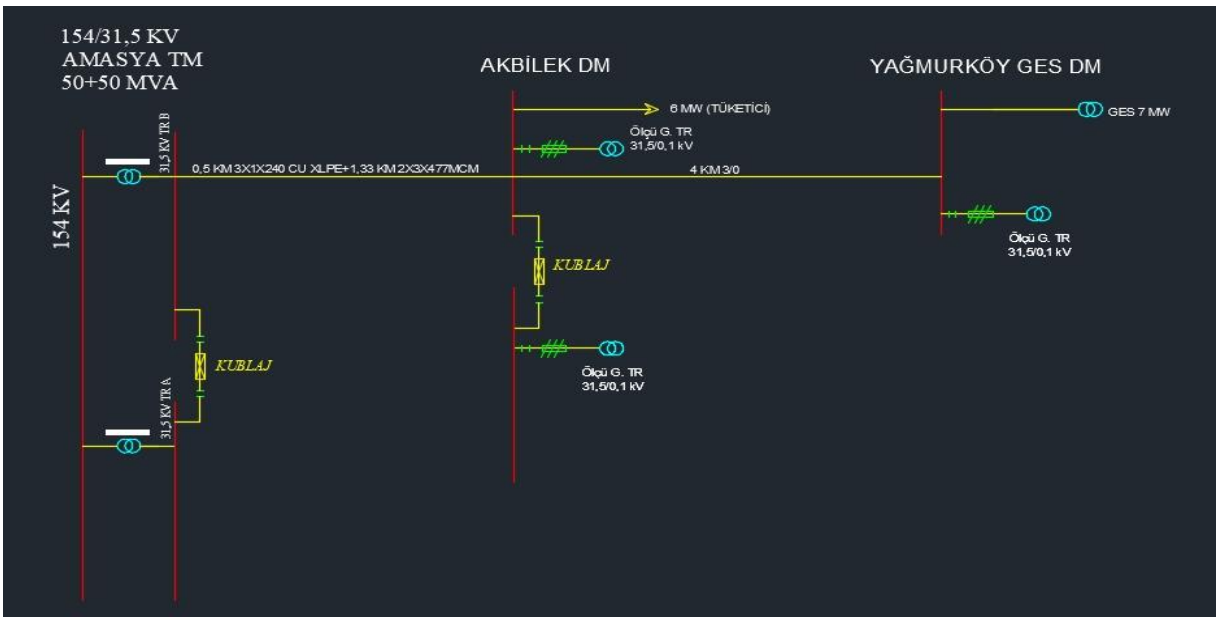
7-Kısıtlılık Durumları

Bir dağıtım şebekesinde kısıtlılık durumları söz konusu olduğunda ilk akla gelen dağıtım merkezleri arası veya fiderler arası ring hatlarıdır. Ring hatlar, genellikle üstünde hiç dağıtım trafosu bulunmayan ve hiçbir özel müşteriye enerji verilmeyen, herhangi bir kısıtlılık durumu için enerjili bekletilen yedek enerji nakil hatlarıdır. Genellikle güç trafolarında çıkan 2 farklı fider veya 2 farklı merkezdeki güç trafolarından gelen fiderlerle sistemin sürekliliği için ring şebekeler tasarlanır.

Kısıtlılık durumlarında, Kaynak olan ikinci alternatif bir güç trafosunda eğer yeteri kadar enerji verebilecek kapasite yok ise bu noktalarda ring hatlarla bağlanıp kaynak pozisyonunda çalışabilecek şebekedeki dağıtık elektrik üretim santralleri önemli bir rol üstlenebilir. Belirli bir zaman diliminde üretim tesisinin kapasitesine bağlı kalarak, şebeke yükünün ring hatlar üzerinden bu üretim tesislerini kaynak olarak kullanacak şekilde referans gerilimin yine bir TEİAŞ trafo merkezinden alınması suretiyle dağıtım şebekesinin enerji ihtiyacı karşılanabilir.

Materyal ve Metot

Şekil 6' da görüldüğü gibi TEİAŞ'a ait olan 154 KV Amasya TM' den enerjili Akbilek Fideri YEDAŞ'a ait olan Akbilek DM' yi beslemektedir. Nominal işletme koşullarında 6 MW yükte çalışan Akbilek DM barasına Yağmur Köyü mevkiinde bağlantı gücü 7 MW olan bir grup güneş santrali bağlandığında gerilimdeki değişim, Digsilent Yazılımı kullanılarak inceleniyor.



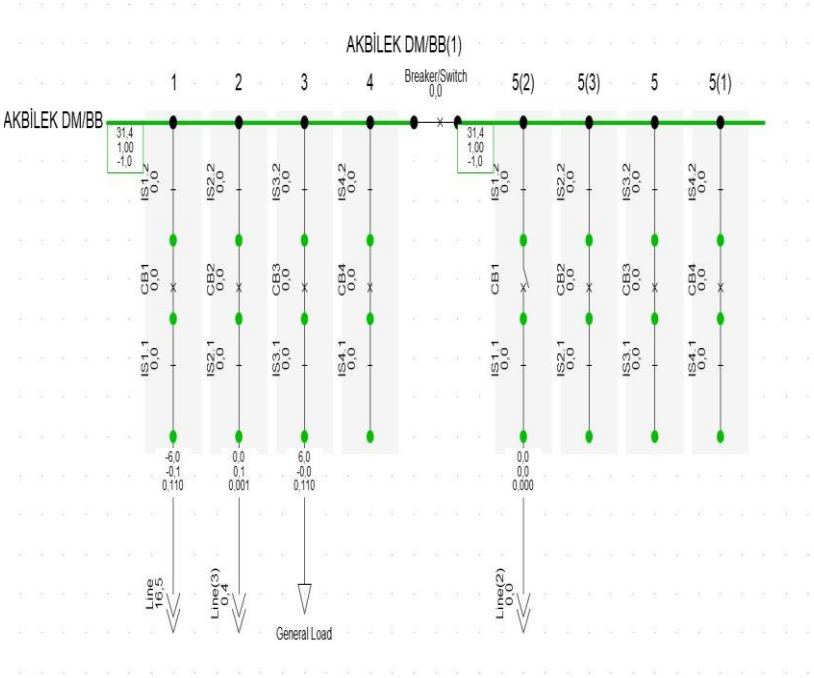
Şekil 6. Akbilek DM digsilent görünümleri

1. Aşama: Yağmurköy Ges Santraller Üretimde değilken Akbilek DM ve Yağmurköy GES DM baralarındaki gerilim değerleri
2. Aşama: Yağmurköy Ges Santraller Üretimdeyken Akbilek DM ve Yağmurköy GES DM baralarındaki gerilim değerleri DM'lerin gerilim ölçü hücreleri üzerinden ölçülmüştür.

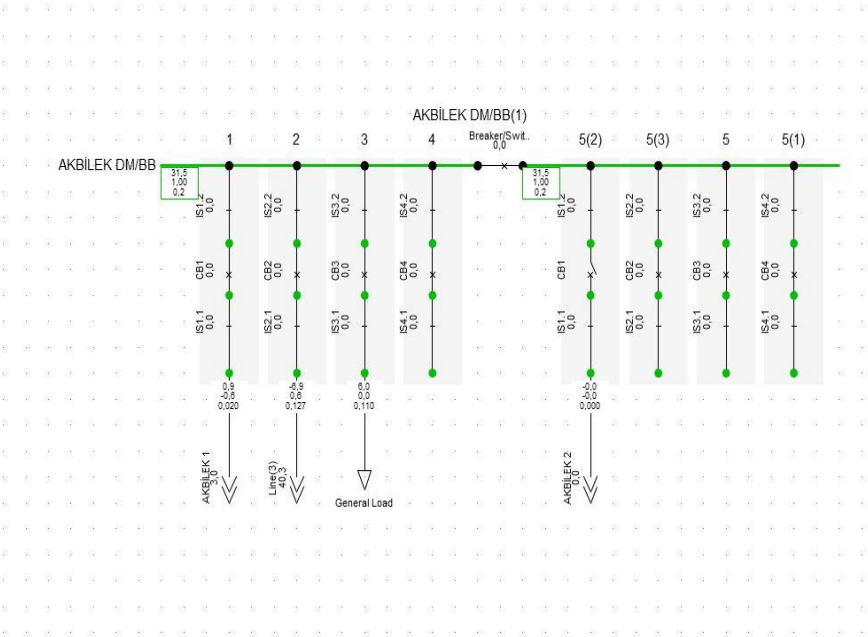
Tablo 1. Digsilent gerilim analizi sonuçları

DM	GES Üretimde Değilken Gerilim	GES Üretimdeyken Gerilim	Gerilimdeki Değişim %
AKBİLEK DM	31,4 kV	31,5 kV	0,30%
YAĞMURKÖY GES DM	31,4 kV	31,7 kV	1%

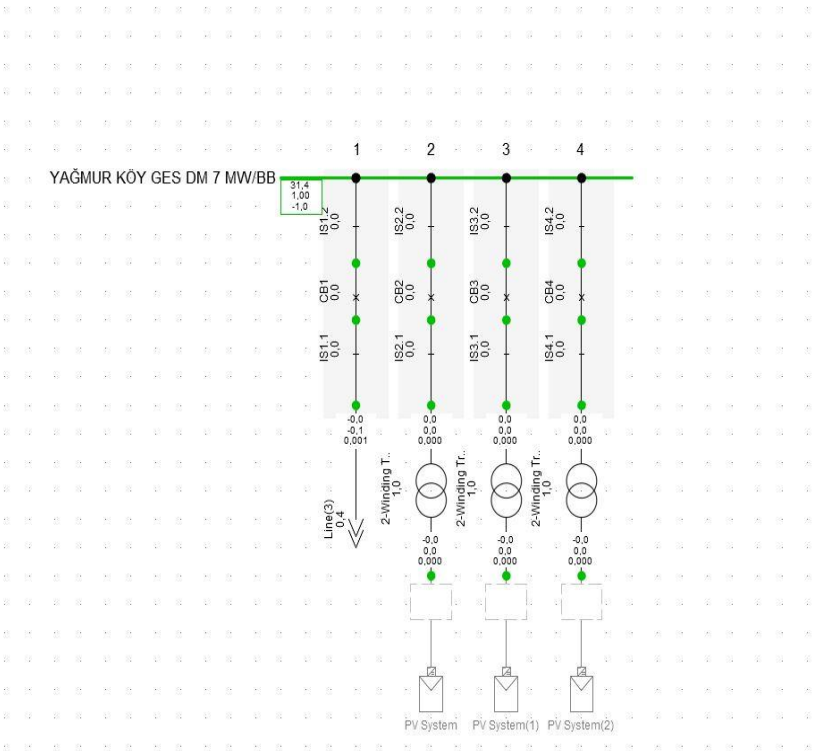
Digsilent yazılımından elde edilen sonuçlar yukardaki tablodan görüleceği üzere, DÜT olan Yağmurköy Ges Santraller üretimdeyken, nominal işletme koşullarına göre Akbilek DM' de gerilim seviyesinde 0,3% artış olduğu gözlemlenmiştir ve bu artış dağıtım şebekesinde gerilimi iyileştirmiştir. Ayrıca +1 MW üretim ile yük akış yönü iletim yönüne doğru değişmiştir. Sonuç olarak, dağıtım şebekesi açısında olumlu bir durum olarak değerlendirilmiştir.



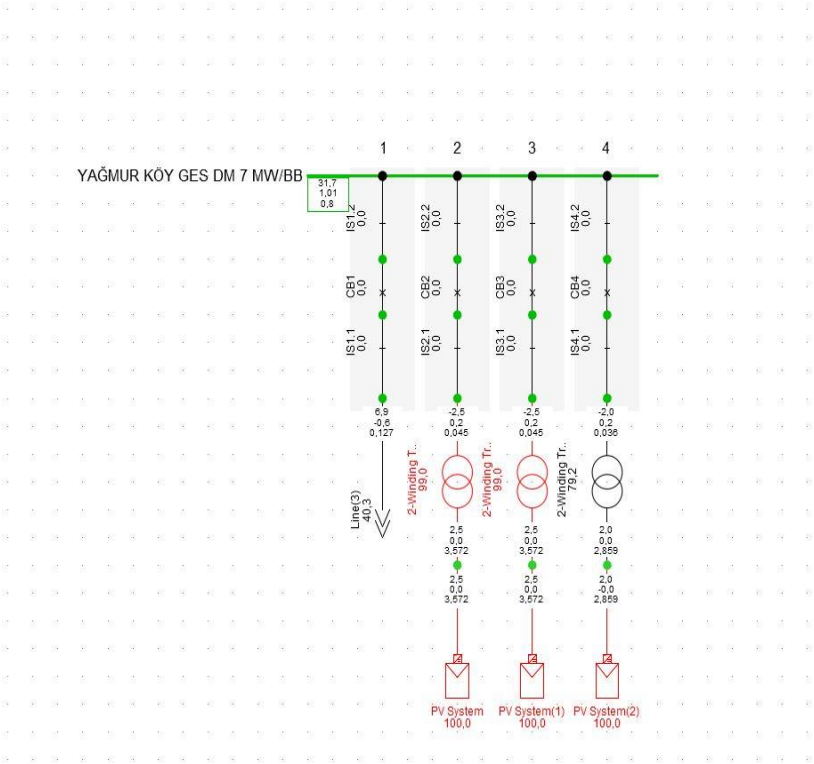
Şekil 7. Akbilek GES santral devre dışı olduğunda



Şekil 8. Akbilek GES santral devrede olduğunda



Şekil 9. Yağmurköy GES santral devre dışı olduğunda



Şekil 10. Yağmurköy GES santral devrede olduğunda

Sonuç ve Öneriler

- Dağıtık üretim tesislerinin dağıtım şebekelerine bağlanmadan önce planlamanın çok iyi yapılması gerekmektedir. Çünkü dağıtım tesisleri, TEİAŞ'a ait trafo merkezlerindeki güç trafolarını esas kaynak olarak baz alır ve sonrasında herhangi bir üretim tesisi bağlanması üzere çift yönlü akışa yol açacak birden

fazla kaynağı olan sistemler olarak düşünülmemiştir. Buradan hareketle, yük akış yönü analizi, güç kalitesi analizi, kısa devre analizi ve koruma analizleri yapılıp, şebekeye uygun sonuçlar elde edilmesi veya ek yatırım ve çalışmalarla uygun olmayan şebekenin uygun hale getirilmesiyle dağıtık üretim tesislerinin bağlanması gerekmektedir.

- Kurulacak üretim sisteminin tipine ve büyüklüğüne göre gerekli analizlerin yapılıp, uygun entegrasyon alternatiflerinin değerlendirilmesi ve sistemi bozucu etkileri varsa, entegrasyon öncesi gerekli önlemlerin alınması gerekmektedir. (Çetinkaya, H. B., & Dumlu, 2013)
- Yerinde ve doğru analizlerle bağlanmamış dağıtık üretim tesisleri en başta can ve mal güvenliğini tehdit eder ve dağıtım şebekesinin teknik kalitesini bozar, aynı zamanda üretimin verimli seviyede kullanılamamasına sebep olur.
- Faydalı yönleriyle kazanımlar sağlayarak şebekede izin verilmiş dağıtık üretim tesisleri ülkemizin enerji arzı ve ilerleyişi açısından büyük anlam ifade etmektedir

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Yeşilırmak Elektrik Dağıtım A.Ş.

A COMPARATIVE ANALYSIS ON THE EFFECT OF PRECIPITATION ON THE ENERGY PRODUCTION OF HYDROPOWER PLANTS

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ABSTRACT

The waning accessibility of fossil fuels, along with an increasing recognition of the phenomenon of global warming, has compelled several states to accord precedence to the utilization of renewable energy sources. Hydropower emerges as the prevailing renewable energy source, comprising a substantial share of the overall renewable energy. The production of energy from hydropower plants is influenced by several factors and conditions. Precipitation is one of the effective parameters that has influence on energy production from hydropower plants. In this study, a comparative work has been conducted on determination of effect of precipitation on energy production. Selected two hydropower plants, in Turkey, have been investigated based on the obtained precipitation and energy production data for two years. Study reveals that there is an obvious correlation between energy output and precipitation when considering monthly average data. However, there is no obvious relationship between the amount of precipitation on a certain day and the amount of energy produced on that particular day.

Keywords: Hydropower plants, Energy production, Precipitation

INTRODUCTION

Precipitation has a significant influence on the development of hydroelectric energy, since it plays a crucial role in determining the efficiency and output of hydropower facilities. Precipitation, whether in the form of rain or snow, plays a crucial role in the water cycle by directly impacting the presence and movement of water in rivers and reservoirs. Precipitation patterns play a vital role in the generation of electricity in hydropower systems, since they determine the flow of water that is used for power generation. Sufficient and regular rainfall is crucial for maintaining adequate water levels in reservoirs and river systems, hence guaranteeing a stable water supply to hydropower plants. Ample precipitation or the melting of snow leads to elevated water levels, hence enhancing the extractable potential energy. On the other hand, lengthy periods of drought or inadequate rainfall may result in decreased water levels, which might affect the plant's ability to produce power. Precipitation fluctuations throughout the year can impact the production of hydropower. During the months when the weather is warmer, the melting of snow and the rise in rainfall may lead to higher water flows, which has a beneficial effect on energy generation. In contrast, periods of low rainfall during dry seasons may provide difficulties for hydroelectric facilities, requiring the use of meticulous water management strategies.

Singh et al. [1] discussed the assessment of the impact of climatic variation on hydropower generation in Nepal, particularly in the context of Run-off-River (ROR) type hydropower projects. The study utilizes the WEAP model and meteorological and hydrological data from 1976 to 2004 to evaluate the potential effects of climate change on hydropower generation. The results indicate that the streamflow of the Dordi River in Nepal is exhibiting increasing trends, particularly during the months of April, May, June, and July under different climatic scenarios. Furthermore, the study suggests that the generation of hydropower plants is likely to increase significantly under these climatic scenarios, with potential increments of up to 15%, 1%–32%, and 1%–51% over the study period under climatic scenarios 1, 2, and 3, respectively, compared to the baseline scenario. These increments are observed to be more prominent during the crucial dry season months of April and May, which is significant given the power deficit experienced during this period in Nepal. Kim et al. [2] studied the effects of climate change on hydropower energy generation and water supply in Manitiba, America. It revealed that the forebay will undergo expansion in the spring and summer, while experiencing contraction in the winter and autumn and the hydropower generating potential will rise throughout the spring, which is the season characterized by increased floods. Similarly, Kopytkovskiy et al. [3] examined the impacts of climate

change on water availability and hydropower plant energy production in Colorado River. It is projected that while precipitation alters 16%, the flow rate changes up to 50%. Furthermore, projections specify that rise in temperature at lower altitudes and a greater variation in seasons at higher elevations. Chiang et al. [4] studied the potential effects of climate change on energy production of hydropower plant in Taiwan. According to the examination, in the dry season, the river discharge varied between 26% and 15%, whereas in the rainy season, it ranged from 10% to 82%. It concluded that climate change may impact Taiwan's hydrology and its capacity to produce hydroelectric electricity. Fan et al. [5] conducted a study on determination of the effects of climate change on hydropower energy production in China. It is stated that the effects of climate conditions on hydropower production vary across the northern and southern areas of China and the impact of rainfall on hydropower production is substantial in the southern areas, but negligible in the northern region. Wang et al. [6] evaluated the influence of climate change on the capacity for hydropower generation in the Nanliujiang River watershed in China and detailed that the range of projected increases in river flow leads to a 7.7% to 15.6% increase in hydropower potentials.

As stated in the aforementioned literature review, various elements and situations have an impact on the generation of electricity from hydropower facilities. Precipitation is a significant factor that directly impacts the generation of electricity from hydropower facilities. This research involves a comparative analysis to determine the impact of precipitation on energy generation. An analysis was conducted on two specific hydropower facilities in Turkey, using data on precipitation and energy output collected over a two-year period. The findings of this study have important implications for policymakers, researchers, and practitioners involved in hydropower generation and climate change adaptation.

MATERIALS AND METHODS

Erik Hydropower Plant

Figure 1 demonstrates the location of studied hydropower plant and region. The Erik Hydropower Plant is situated along Meydancık Stream in Şavşat, Artvin. With an installed capacity of 15.6 MW, the plant generates a substantial 40 GWh of energy annually. Its key components include the Erik Regulator (Intake), Transmission Tunnel, Penstock, and Power House. The transmission tunnel and channel extend over a substantial length of 2700 meters, while the penstock, measuring 250 meters, further directs the water flow towards the powerhouse. Operating with a project flow of 20 m^3/s, the Erik Hydropower Plant employs Francis turbines.

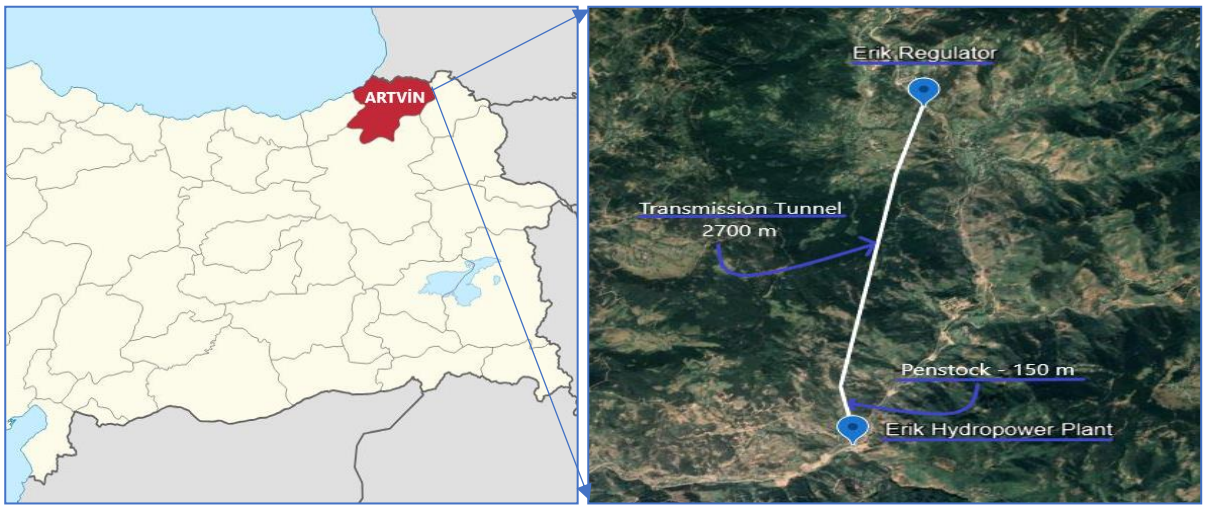

Figure 1. The location of Erik Hydropower Plant

The mentioned technical specifications of Zilan HPP are summarized in the Table 1.

Table 1. Technical specifications of Erik HPP

Location	**Meydancık Stream/ Şavşat /Artvin**
Installed Capacity	15.6 MW
Energy Production	40 GWh/year
Plant Components	Erik Regulator (Intake)
	Transmission Tunnel
	Penstock
	Power House
Transmission tunnel and channel	Length: 2700 m
Penstock	Length: 250 m
Project Flow	20 m³/s
Turbine Type	Francis

Figure 2 and 3 show the daily energy production of Erik HPP for 2021 and 2022, respectively. It can be derived from the figures that the most energy production of power plant is accumulated between March and June, for both years. For the rest of year, especially between September and December, the occurrence of energy generation is lower than the months of spring season.

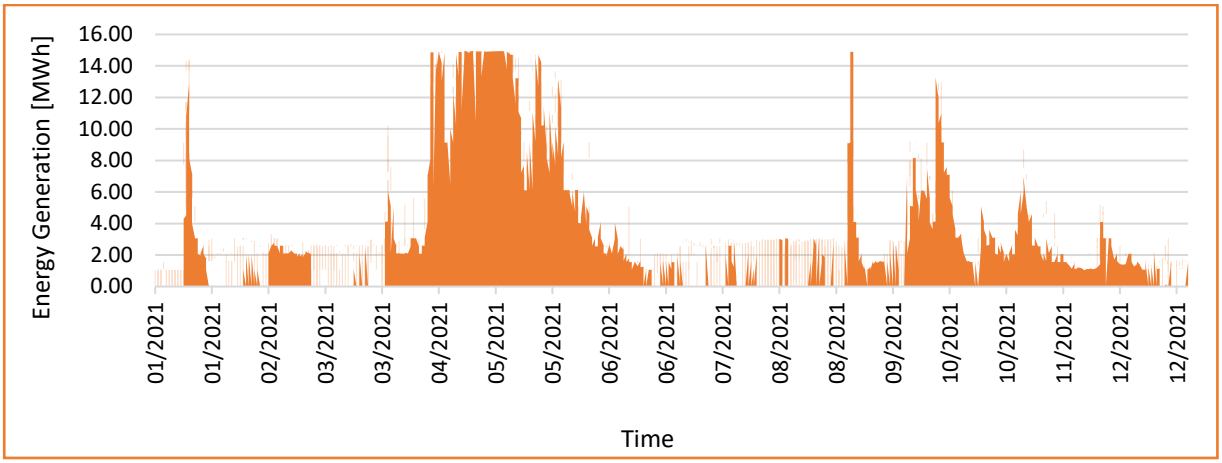

Figure 2. Daily energy production of Erik HPP in 2021

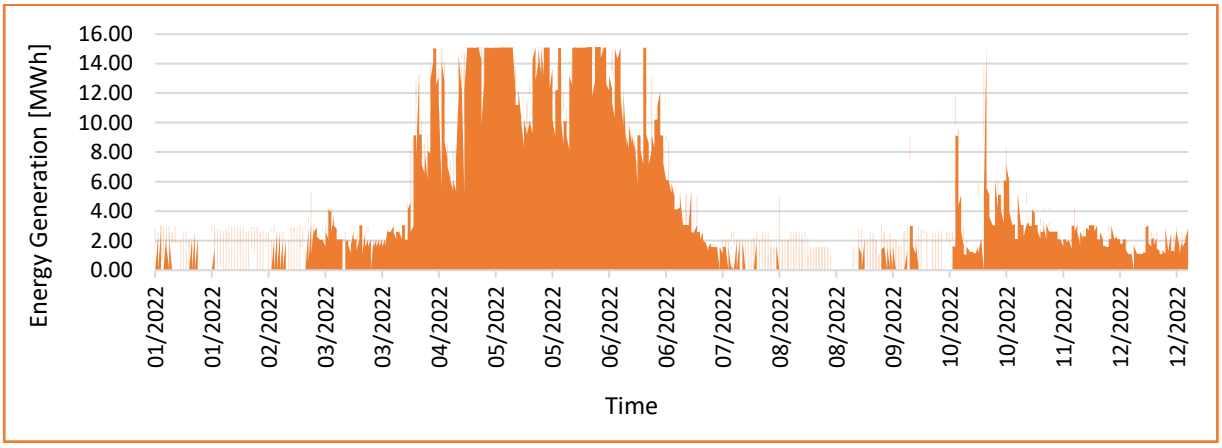

Figure 3. Daily energy production of Erik HPP in 2022

The precipitation patterns that occurred in Savsat province, which is the location of the power plant that was investigated (Erik HPP), are shown in Figure 4 for the years 2021 and 2022. It clearly seen from the figure that precipitation occurs throughout the year, for both years.

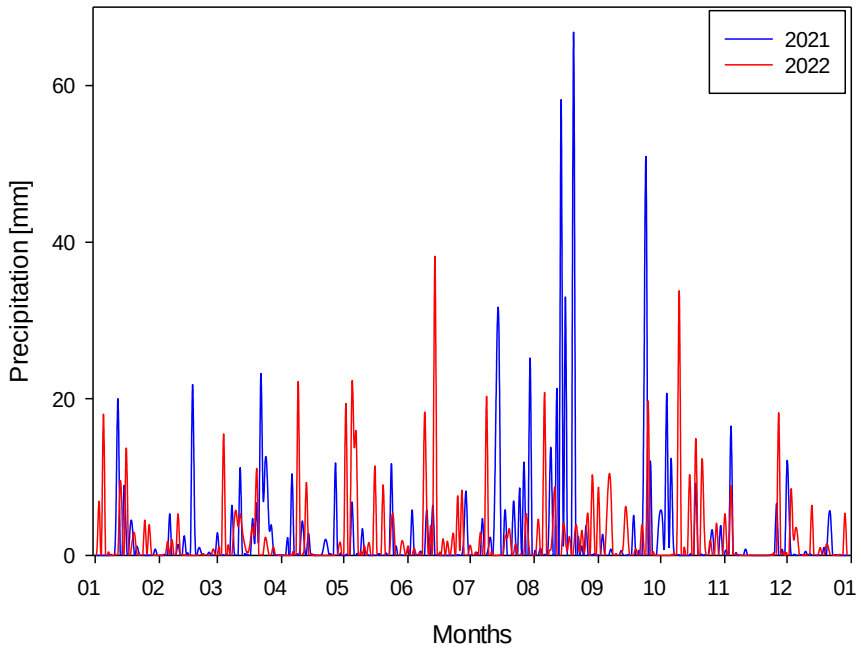

Figure 4. Precipitation characteristics of Savsat Province

Zilan Hydropower Plant

Figure 5 shows the location of the Zilan HPP, which uses in the comparison. The Zilan HPP is located on the Zilan Stream having an installed capacity of 6.32 MW, this facility annually produces 20 GWh of clean and renewable power. The plant's integral components include the Zilan Regulator (Intake), Transmission Tunnel, Penstock, and Power House, each playing a crucial role in the energy production process. The transmission tunnel and channel stretch an impressive 3900 meters, efficiently guiding the flow of water to harness its potential. Further enhancing its capabilities, the plant features a lengthy penstock measuring 1070 meters, directing the water towards the powerhouse. Operating with a project flow of 10 m³/s, the Zilan Hydropower Plant employs the Francis turbine type, known for its reliability and efficiency in converting water energy into electrical power.

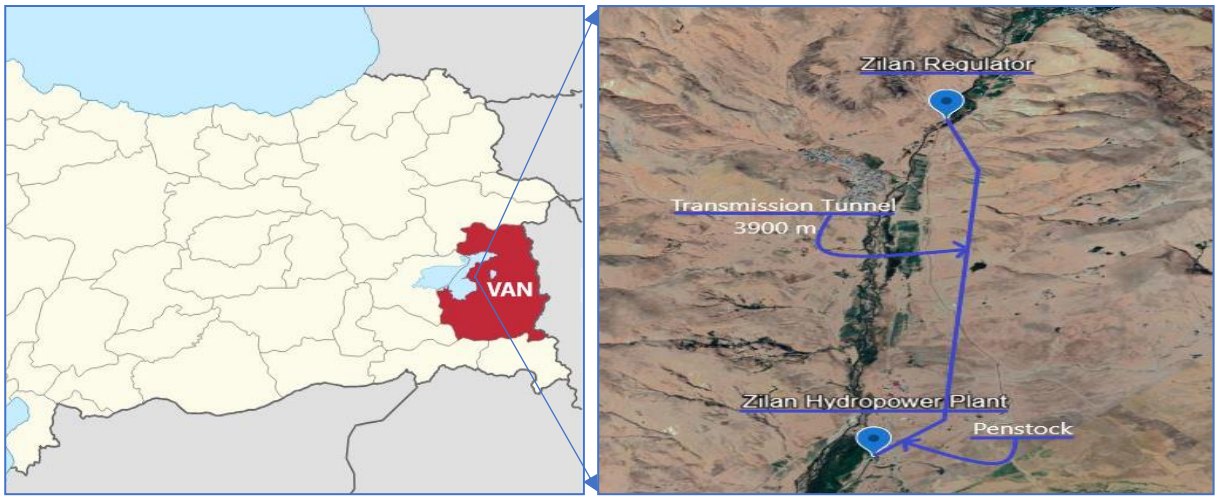

Figure 5. The location of Zilan Hydropower Plant

The technical specifications mentioned above of Zilan HPP is summarized in the Table 2.

Table 2. Technical specifications of Zilan HPP

Location	**Zilan Stream/Ercis/Van**
Installed Capacity	6.32 MW
Energy Production	20 GWh/year
Plant Components	Zilan Regulator (Intake)
	Transmission Tunnel
	Penstock
	Power house
Transmission tunnel and channel	Length: 3900 m
Penstock	Length: 1070 m
Project Flow	10 m³/s
Turbine Type	Francis

The daily energy output of Zilan HPP is shown in Figures 6 and 7, respectively, according to the years 2021 and 2022. Based on the data, it is possible to deduce that the period of time between the end of March and June is when the power plant generates the greatest amount of energy, and this holds true for both years. When compared to the months that fall within the spring season, the amount of energy that is generated throughout the rest of the year is much smaller.

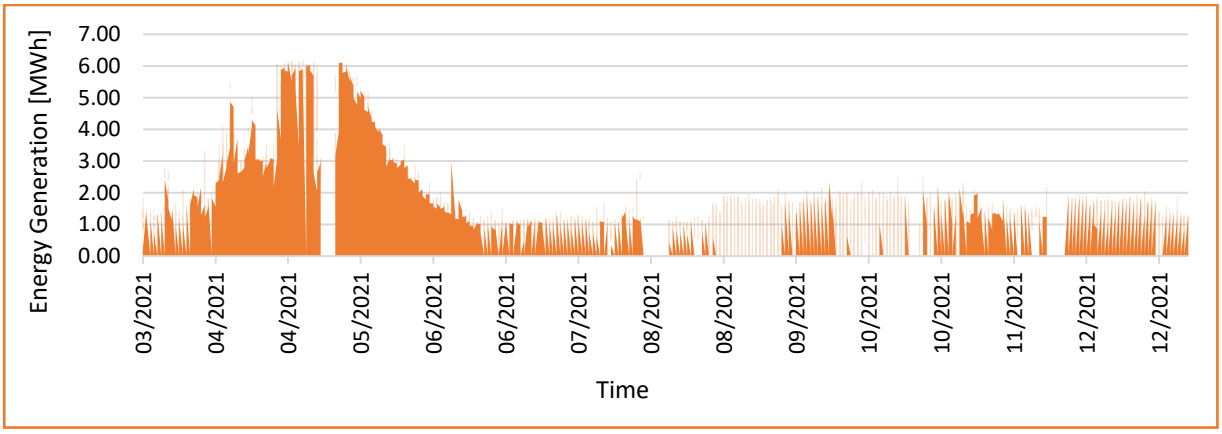

Figure 6. Daily energy production of Zilan HPP in 2021

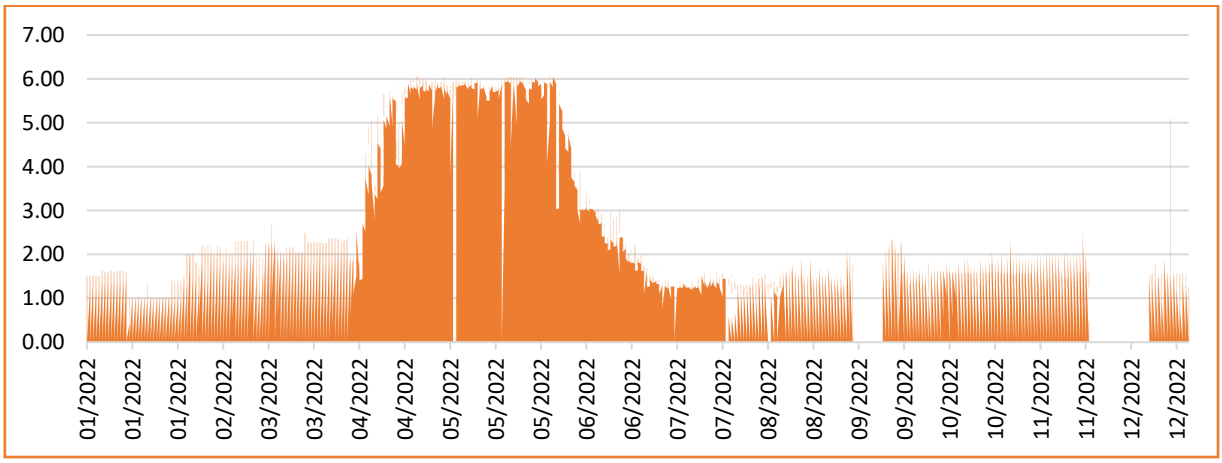

Figure 7. Daily energy production of Zilan HPP in 2022

Figure 8 depicts the patterns of precipitation that took place in the province of Ercis, which is the site of the power plant that was researched (Zilan HPP). These patterns are given for the years 2021 and 2022. The chart makes it very evident that the great bulk of precipitation typically takes place between the months of January and May, while nearly little precipitation takes place between the months of August and October, for both years.

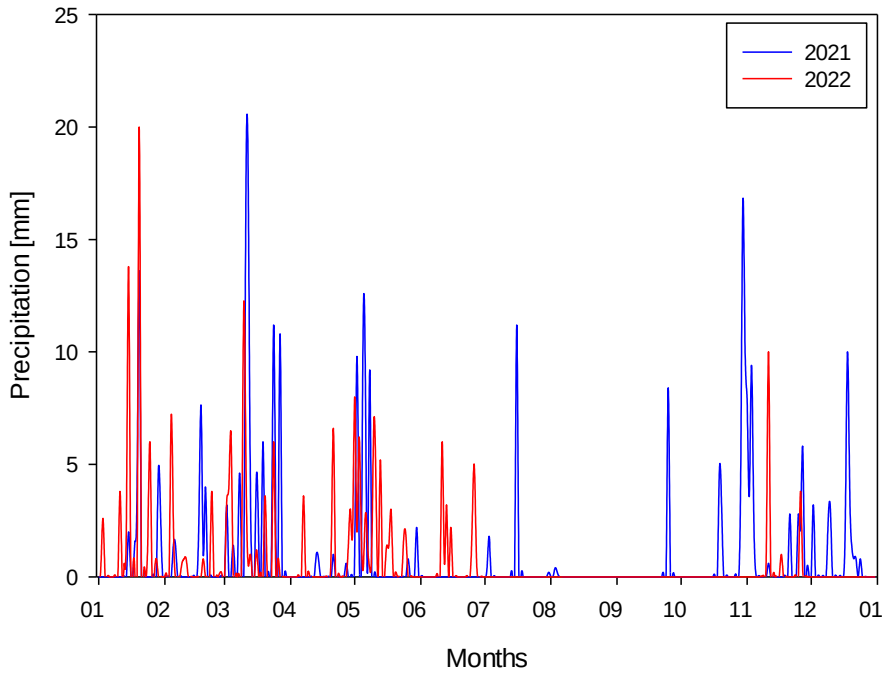

Figure 8. Precipitation characteristics of Ercis

RESULTS AND DISCUSSION

Hydropower facilities are subject to a number of situations and factors that may have an effect on the amount of energy they generate. The amount of precipitation that falls on a landscape is one of the most important factors that determines the amount of electricity that hydropower plants generate. For the purpose of this investigation, a comparative analysis has been carried out to determine the impact that precipitation has on the generation of potential energy.

Figure 9 presents a comparison of the precipitation characteristics of the provinces that were analyzed for the years 2021 and 2022. These provinces are the states in which hydropower plants are situated, where Ercis for Zilan HPP and Savsat for Erik HPP.

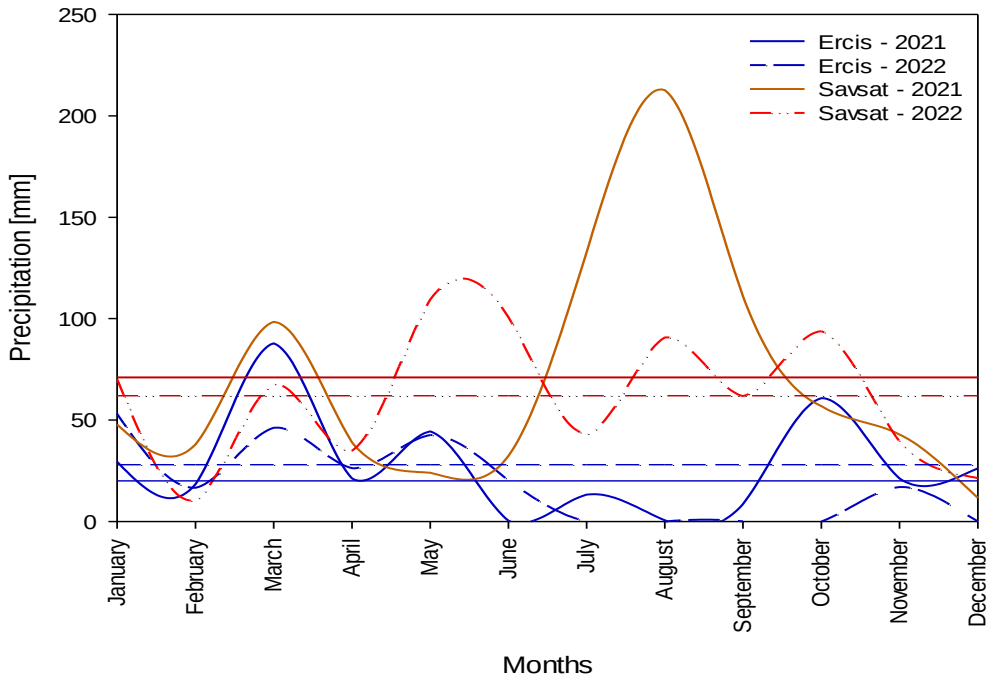

Figure 9. Comparison of monthly precipitation rates of regions

The precipitation characteristics of studied regions shows different patterns. While recorded average precipitation of Savsat region is nearly 65 mm, the average precipitation of Ercis region is 25 mm. there exists an extreme difference between studied provinces. There are no rain or snowfalls during the months of June and September, for Ercis Province. However, in Savsat province the precipitation occurs in whole year. This outcome directly affects the energy production characteristics of hydropower plants, that are located in these regions.

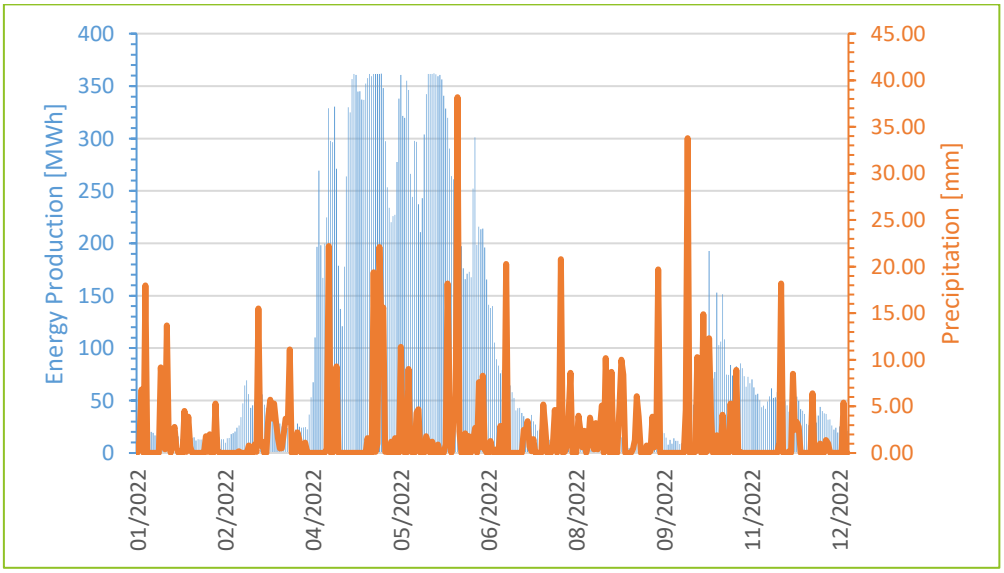

Figure 10. Daily energy production versus precipitation in 2022 – Erik

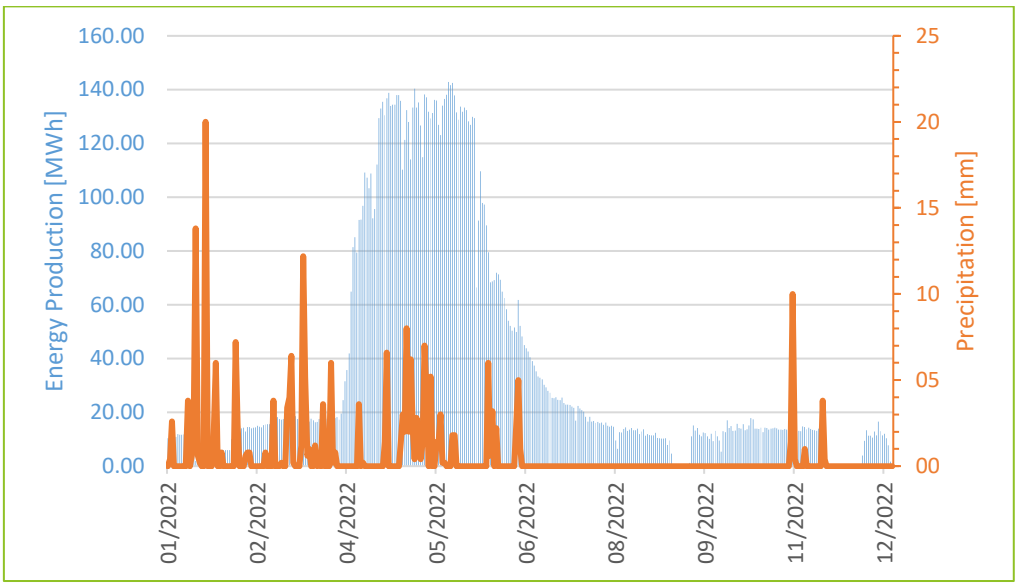

Figure 11. Daily energy production versus precipitation in 2022 – Zilan

With regard to the year 2022, Figures 10 and 11 illustrate the relationship between the daily energy output and the daily precipitation at selected hydropower plants belonging to the Erik and Zilan HPP, respectively. It can be derived from the figures that for both hydropower facilities, there is no correlation between the amount of energy produced each day and the amount of precipitation that falls each day.

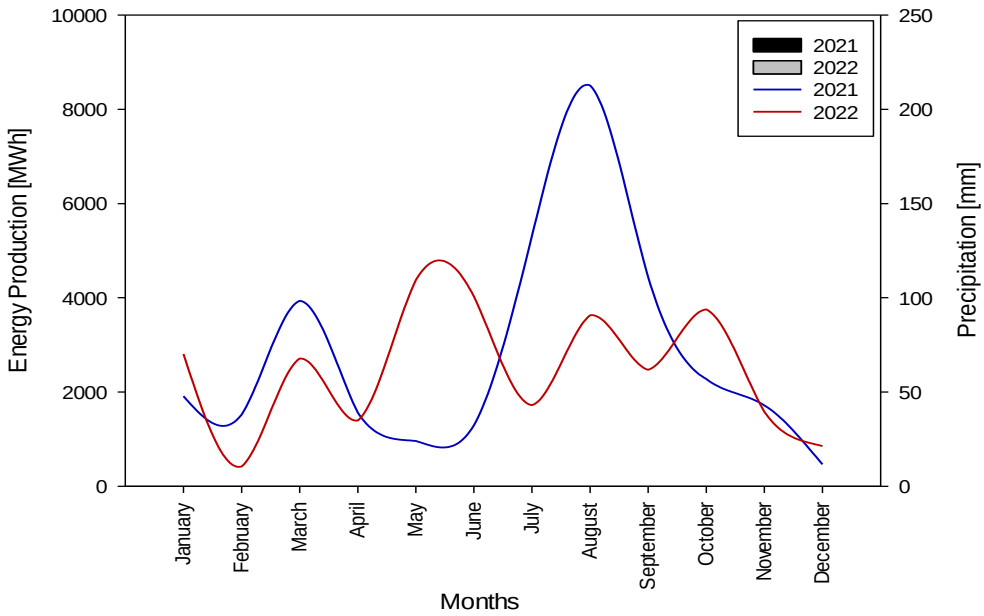

Figure 12. Variation of monthly energy production with respect to precipitation – Erik HPP

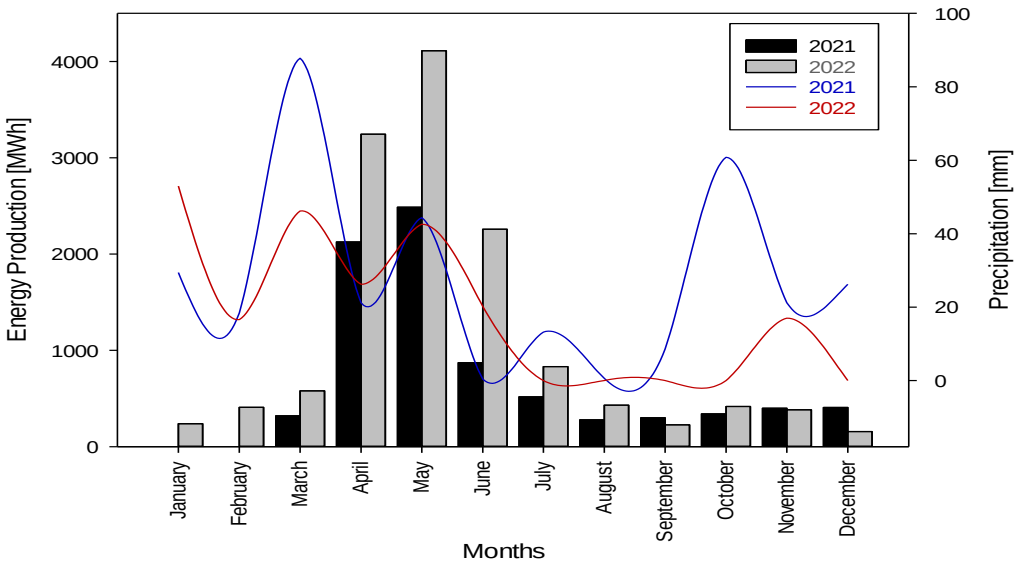

Figure 13. Variation of monthly energy production with respect to precipitation – Zilan HPP

Figure 12 and 13 illustrate the variation of monthly energy production with respect to precipitation for Erik HPP and Zilan HPP, respectively. It is possible to infer from the figures that there is a connection between the amount of precipitation, and the flow rate throughout the spring season, which includes the months of March, April, May, and June. First, the precipitation rate grows and reaches a peak level in the figures that have been provided, and then the energy generations also increase and reach a peak, which represents a changing data of precipitation for the months that have been specifically mentioned.

CONCLUSION

Hydropower facilities are subject to a number of situations and factors that may have an effect on the amount of energy they generate. The amount of precipitation that falls on the surroundings is one of the most important factors that determines the amount of electricity that hydropower plants generate. For this investigation, a comparative analysis has been carried out to determine the impact that precipitation has on the generation of potential energy. It is deduced that there is a clear correlation between energy output and precipitation when looking at monthly average statistics and the summer precipitation had little impact on energy generation. Furthermore, precipitation and energy generation both see a rise, particularly during the spring season.

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SYNTHESIS AND CHARACTERIZATION OF $Pd_xNb_{(100-x)}$/CNT ANODE CATALYSTS FOR ETHYLENE GLYCOL ELECTROOXIDATION

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ABSTRACT

With increasing energy demand and the rapid depletion of traditional fossil fuels, the development of clean and efficient power sources has attracted the attention of researchers in recent years. Direct liquid-fed fuel cells are considered the ideal power conversion system for this purpose. Among various fuel cells, direct ethylene glycol fuel cells (DEGFCs) stand out with lower toxicity, less volatility and high electrical power conversion efficiency. At the anode side of DEGFCs, ethylene glycol (EG) electrooxidation reaction takes place. Therefore, designing anode catalysts with high activity and stability for EG electrooxidation is crucial for the performance of DEGFCs. In addition, reducing the noble metal ratio of fuel cell anode catalysts is an important strategy to reduce the total cost. Accordingly, carbon nanotube (CNT) supported $Pd_{90}Nb_{10}$, $Pd_{80}Nb_{20}$, $Pd_{70}Nb_{30}$, $Pd_{60}Nb_{40}$ and $Pd_{50}Nb_{50}$ anode catalysts were prepared by $NaBH_4$ reduction method. PdNb/CNTs prepared at varying atomic molar ratios were characterized by X-ray diffraction (XRD), transmission electron microscopy (TEM) and inductively coupled plasma-mass spectrometry (ICP-MS). The $Pd_{50}Nb_{50}$/CNT catalyst outperformed the other ratios with a specific activity of 9.02 mA cm^{-2} for EG electrooxidation. In addition, $Pd_{50}Nb_{50}$/CNT catalyst was found to be both more stable and lower charge transfer resistance than other catalysts.

Keywords: Fuel cell, ethylene glycol, electrooxidation, palladium, niobium.

Introduction

The creation of innovative, clean, highly efficient alternative power sources has drawn a lot of attention in recent years due to the rising energy demands and the quick depletion of conventional fossil fuels (Mahapatra, Kumar et al. 2021). Fuel cells are thought to be excellent options when fed with hydrogen, methanol, ethylene glycol (EG), and other renewable resources. Numerous researchers are fascinated by direct EG fuel cells (DEGFCs), one of the many types of fuel cells that have less volatility, a higher boiling point, reduced toxicity, and high electric power conversion efficiency (Fashedemi, Miller et al. 2015). The roles that catalyst materials play are vital in fuel cells. Here, Pd-based electrocatalysts have made significant strides in the last few decades for the use of direct alcohol fuel cells (DAFCs). However, the commercial production of Pd-based electrocatalyst material is hindered by its disadvantages, which include high cost, modest catalytic activity, and limited durability (Assad, Tariq et al. 2023). There are two very feasible solutions to address these issues. One way to lower costs is to replace or alloy palladium with other transition metals, hence reducing its use (Chen and Ostrom 2015). Additionally, it has been demonstrated that combining palladium with other non-noble metals using is an effective way to develop exceptional Pd-based electrocatalysts. Numerous researchers from all over the world have worked very hard in this topic.

Ren et al. prepared Pd/RGO-MnO_2 electrocatalysts with varying MnO_2/RGO ratios and reported a mass activity of 4741.18 mA mg^{-1} for EG electrooxidation. They also emphasized that the equimolar MnO_2/RGO ratio provides advantages in terms of CO poisoning tolerance and charge transfer resistance for EG electrooxidation. The high activity was attributed to the bifunctional effect of MnO_2 (Ren, Chen et al. 2021). Hefnawy et al. synthesized RGO-supported NiMn catalysts for EG electrooxidation. RGO has not been used as a conventional support material. NiMn was deposited layer by layer on RGO. The obtained NiMn/RGO composite showed very high performance for both EG electrooxidation and hydrogen evolution reaction. Researchers reported that NiMn/RGO showed a specific activity of 38 mA cm^{-2} for EG electrooxidation (Hefnawy, Fadlallah et al. 2021). In the study conducted by Zou et al., PdPb electrocatalysts were synthesized. Researchers have reported the effect of Pd/Pb atomic molar ratio on EG electrooxidation activity. Accordingly,

they reported the mass activity of the $Pd_{65}Pb_{35}$ catalyst for EG electrooxidation as 4.47 A mg Pd_{-1}. It was also emphasized that the electrocatalyst in this ratio is more stable than other ratios (Zou, Zhang et al. 2022). Liu et al. investigated the activity of CoO-NiO supported Pd catalysts for EG electrooxidation. They determined the mass activity of the Pd/CoO-NiO electrocatalyst as 2980.83 mA mg^{-1} Pd. Researchers explained the developing electrocatalytic activity with the synergistic effect between Co, Ni and Pd metals (Liu, Wu et al. 2022).

In this study, carbon nanotube (CNT) supported PdNb catalysts at different atomic molar ratios were prepared by the sodium borohydride reduction method. The electrochemical activities and stability of $Pd_{90}Nb_{10}$/CNT, $Pd_{80}Nb_{20}$/CNT, $Pd_{70}Nb_{30}$/CNT, $Pd_{60}Nb_{40}$/CNT, and $Pd_{50}Nb_{50}$/CNT catalysts were determined by cyclic voltammetry (CV), chronoamperometry (CA), and electrochemical impedance spectroscopy (EIS). It was concluded that the examined PdNb/CNT catalysts were promising anode catalysts for EG electrooxidation.

Materials and Methods

PdNb/CNT catalysts were prepared by conventional chemical reduction method. Sodium borohydride was used as the reducing agent. First of all, CNT was dissolved in pure water and Potassium tetrachloropalladate(II) (K_2PdCl_4) and Niobium(V) chloride (NbCl) were added to the solution. The solution was made homogeneous by ultrasonic mixing for a certain period of time. Then, the determined amount of $NaBH_4$ was added dropwise to the solution and stirred for 6 hours. Finally, the solution was filtered, washed and dried. With this protocol, $Pd_{90}Nb_{10}$/CNT, $Pd_{80}Nb_{20}$/CNT, $Pd_{70}Nb_{30}$/CNT, $Pd_{60}Nb_{40}$/CNT, $Pd_{50}Nb_{50}$/CNT, Nb/CNT and Pd/CNT catalysts were prepared.

Electrochemical experiments were carried out in the presence of 0.5 M EG in 1 M KOH at a scan rate of 50 mV s^{-1}. A CHI 660 E potentiostat with a conventional three electrode cell was used for electrochemical measurements. Pt wire, glassy carbon electrode and Ag/AgCl electrode were used as counter electrode, working electrode and reference electrode, respectively. To prepare the working electrode, 3 mg of the prepared catalyst was dissolved in 1000 µl Nafion and 4 µl of this solution was transferred to the glassy carbon electrode surface. The modified electrode is dried at room temperature for 24 hours. The prepared three electrode system is immersed in the electrochemical cell and N_2 is passed through the cell before measurements. CV, CA and EIS methods were used for electrochemical characterization of catalysts.

Findings and Discussion

XRD analysis was applied to determine the crystal phases of $Pd_{50}Nb_{50}$/CNT catalysts and is given in Figure 1. The diffraction peak detected at 25.6° 2Θ angle originates from the C (0 0 2) surface (Myoung, Kang et al. 2006). Diffraction peaks indicating Pd (1 1 1), Pd (2 0 0), Pd (2 2 0) and Pd (3 1 1) surfaces were detected at 39.9°, 46.3°, 67.5° and 80.1° 2Θ angles, respectively (Xu, Wu et al. 2008). It was determined that Pd in the catalyst structure has a face center cubic crystal structure. The diffraction peaks observed at 38.6°, 55.6°, 69.7° and 82.5° 2Θ angles were assigned to the (1 1 0), (2 0 0), (2 1 1) and (2 2 0) planes of Nb (Shi, Zhang et al. 2019).

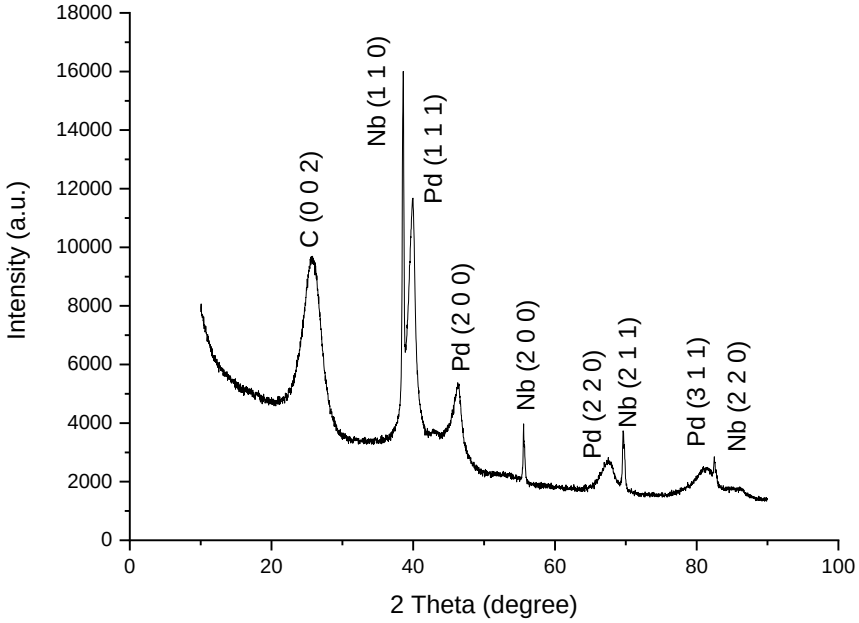

Figure 1. XRD pattern of $Pd_{50}Nb_{50}$/CNT

TEM images of the $Pd_{50}Nb_{50}$/CNT catalyst are shown in Figure 2. It can be seen from Figure 2 that Pd and Nb nanoparticles are well dispersed on the CNT surface. It has been determined that nanoparticles adhere to both the inner and outer walls of CNT. Additionally, the average particle size was calculated as 6.12 nm.

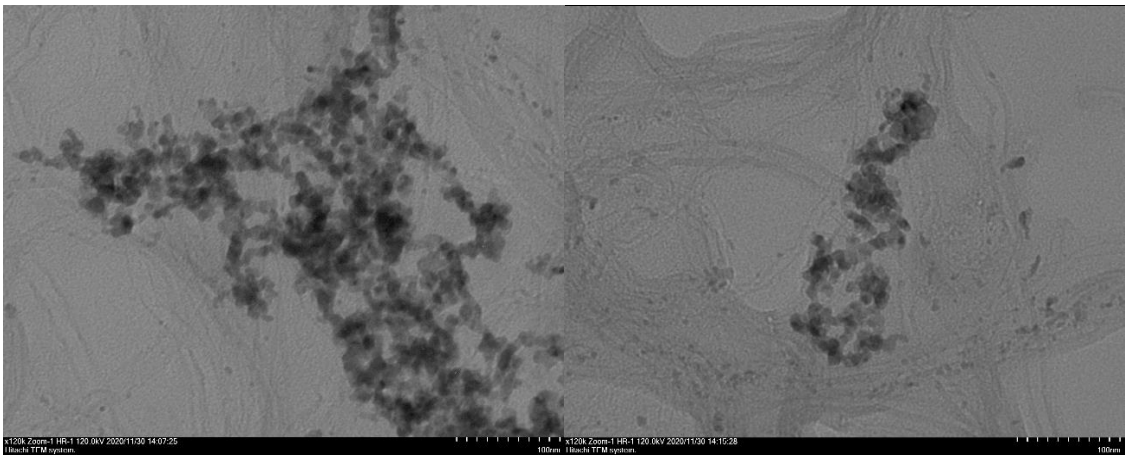

Figure 2. TEM images of $Pd_{50}Nb_{50}$/CNT

Atomic molar ratios of the $Pd_{50}Nb_{50}$/CNT catalyst were confirmed by ICP-MS. The molar Pd/Nb ratio was determined as 43.2/56.8. The closeness of the targeted and obtained atomic molar ratios indicates that the metals can be loaded onto the surface well. Additionally, from the characterization results, it was concluded that the PdNb/CNT catalyst could be synthesized successfully.

Figure 3 shows the CV curves of Nb/CNT, Pd/CNT and PdNb/CNT catalysts in 1 M KOH and 0.5 M EG+1 M KOH solutions. From Figure 3a, it was determined that the electrochemically active surface area of the $Pd_{50}Nb_{50}$/CNT catalyst was higher than the catalysts at other ratios. In the presence of EG, as expected, the $Pd_{50}Nb_{50}$/CNT electrocatalyst exhibited higher electrocatalytic activity than the catalysts at other ratios.

$Pd_{50}Nb_{50}$/CNT catalyst showed 1.85 times higher electrochemical performance than Pd/CNT with a specific activity of 9.02 mA cm^{-2} for EG electrooxidation. The increased electrocatalytic activity with Nb addition was attributed to the synergistic effect between Pd and Nb (Taylor, Ndifor et al. 2008).

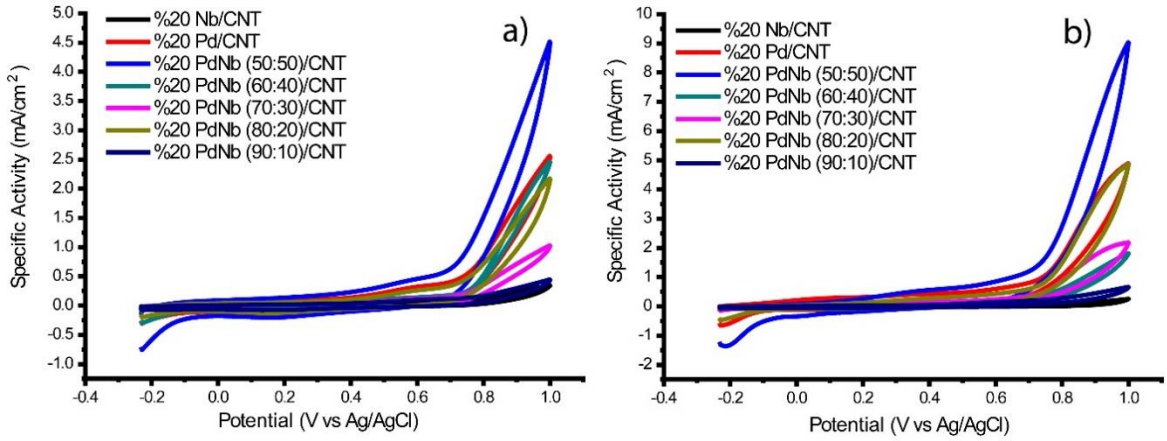

Figure 3. CVs of PdNb/CNTs in a) 1 M KOH and b) 1 M KOH+0.5 M EG

Figure 4 shows the CA and EIS profiles of the synthesized catalysts. From Figure 4a and b, it can be seen that the $Pd_{50}Nb_{50}$/CNT catalyst is more stable at higher specific activity than Pd/CNT and Nb/CNT. In both CA curves, it is seen that the electrochemical activity of Nb is very low. The initial current decreases in the first 30 seconds are due to carbonaceous intermediate products accumulated on the electrode surface. From the EIS profiles of Pd/CNT and $Pd_{50}Nb_{50}$/CNT catalysts at 0.4 V and 1 V potentials, it can be seen that the EIS profile of $Pd_{50}Nb_{50}$/CNT has a smaller circle diameter. Therefore, the charge transfer resistance of Pd/CNT is higher than $Pd_{50}Nb_{50}$/CNT. In other words, electrocatalytic activity was enhanced by the addition of Nb.

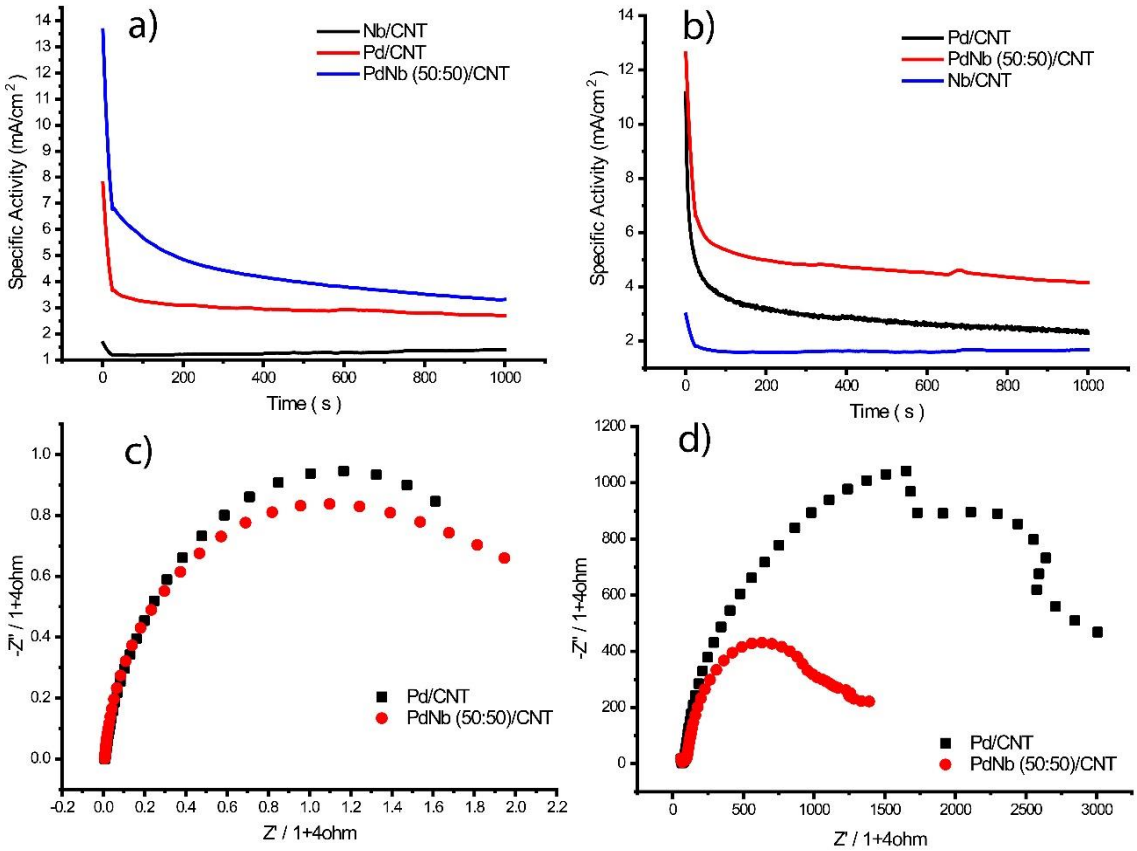

Figure 4. CAs of PdNb/CNTs at a) 0.4 V and b) 1 V potential

Conclusion and Recommendations

PdNb/CNT catalysts were synthesized by the $NaBH_4$ reduction method at varying atomic molar ratios. TEM results show that the particles do not agglomerate on the CNT and are distributed homogeneously. The average particle size was determined as 6.12 nm from TEM photographs. ICP-MS results show that the catalysts were synthesized very close to the desired atomic molar ratios. XRD results also indicate that the PdNb alloy was successfully synthesized. The $Pd_{50}Nb_{50}$/CNT catalyst exhibited a specific activity of 9.02 mA cm^{-2} for EG electrooxidation. In addition, $Pd_{50}Nb_{50}$/CNT has better stability and lower charge transfer resistance than other catalysts. $Pd_{50}Nb_{50}$/CNT catalyst is a good anode catalyst candidate for DEGFCs.

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POWER-AWARE RECONFIGURATION MANAGER FOR SMARTPHONES

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ABSTRACT

We systematically present the development of a power-aware reconfiguration manager tailored for smartphones. In this study, we focus on the reconfigurable regions within the System on Chip (SoC) of smartphones, specifically within the individual tiles, where we select the most suitable alternative tasks in order to create an energy-efficient manager. We accomplish this through symbolic discrete control synthesis. By selecting the most appropriate tasks within the reconfigurable tiles, our manager minimizes energy consumption, contributing to the overall power efficiency of smartphones. The combination of symbolic discrete control synthesis, safety considerations, and optimization strategies provides a robust framework for achieving the dual goals of system reliability and energy optimization. Our empirical findings and results, showcased in an application, underscore the effectiveness of our approach in real-world smartphone scenarios. We validate our approach through a practical application, demonstrating its significant efficiency.

Keywords: Discrete Event Systems, Symbolic Discrete Controller Synthesis, Safety Algorithm, Optimization Algorithm, Smartphones

Introduction

In today's mobile landscape, the capabilities and performance of smartphones have seen significant advancements, yet battery capacities have not kept pace. This has given rise to significant challenges, most notably the untimely depletion of battery power. To address this issue, particularly during times of dwindling battery life, we present the “Power-aware Reconfiguration Manager for Smartphones”. Our solution is aimed at optimizing the utilization of remaining battery power, allowing users to make the most of their devices even when facing low battery conditions. By systematically managing power-aware reconfiguration, our approach seeks to mitigate the adverse impact of limited battery capacity, enhancing the overall smartphone experience.

Initially, our approach revolves around the assessment of the performance and energy characteristics of alternative tasks that can operate within the reconfigurable tiles of smartphones. Here, we take into account these assessments in a methodical manner as we go along, considering the modeling of these activities in the context of a Kahn Process Network (Tripakis et al., 2016, Lee and Parks, 1995, Marwedel, 2006). With the use of this methodology, we can select and reconfigure tasks with confidence, maximizing battery life and performance while guaranteeing the smooth operation of the smartphone. We successfully capture the dynamics of these tasks and their interactions by applying the Kahn Process Network model, which makes it easier to comprehend the behavior of the system as a whole.

Discrete control synthesis was originally conceived as a concept in formal language theory, primarily attributed to (Ramadge and Wonham, 1989, Cassandras and Lafortune, 2007). This theoretical framework primarily revolves around the objective of creating a controller for a given system. Consequently, the earliest endeavors in this field were pursued by (Marchand et al., 2000, Marchand and Samaan, 2000, Marchand and Borgne, 1998). Building upon this foundational work, contemporary advancements in discrete control synthesis, represented by (Berthier and Marchand, 2014, Berthier and Marchand, 2015), have significantly expanded and refined the methodologies involved. These developments have not only widened the scope of applications but have also refined the precision and effectiveness of control synthesis techniques.

In addition to its theoretical underpinnings, discrete control synthesis has found diverse applications across various systems. For instance, it has been applied to address energy efficiency concerns in hardware circuits (Özbaltan and Berthier, 2018, Özbaltan and Berthier, 2020, Özbaltan and Berthier, 2021).

The remainder of the paper is organized as follows: Section 2 gives the materials and our methodology for achieving Power-aware Reconfiguration Manager for Smartphones by using symbolic control. In section 3 we experimentally evaluate our approach and show the results. At last, Section 4 concludes with conclusions and future works.

Materials and Methods

In this study, we aim to overcome shared resource constraints by reconfiguring components within the reconfigurable regions of System on a Chip (SoC) present in smartphones. This is particularly critical in moments where power efficiency is paramount, such as when the battery level is low. Rather than focusing solely on the total energy expended, we emphasize the accurate management of energy within a specific time frame.

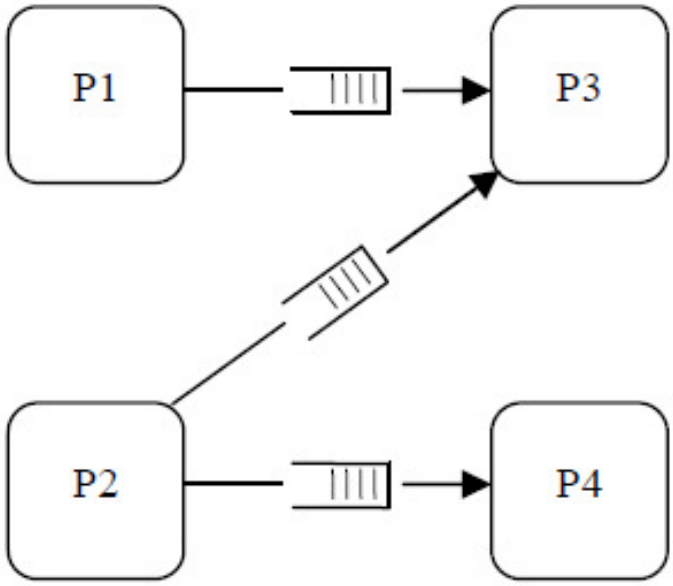

Figure 1. ***Example of Kahn Process Network Model***

On the chip, tasks processed within tiles can have various configurations. Taking this into consideration, we dynamically optimize the design to ensure the most efficient configuration. Simultaneously, we benefit from the reliability of the discrete controller synthesis technique by implementing a safety algorithm to ensure the system's behavior meets the required standards.

In our approach, we model this process using the Kahn Process Network as in Figure 1. This modeling technique is particularly well-suited for addressing the discrete control synthesis problem that we are tackling, as it enables the modeling of process behaviors and the facilitation of data flow between them. In this context, we employ two distinct models: one for tokens and another for processes. These models are expressed as equations in a dataflow language and are encoded in parallel and synchronously.

Subsequently, we leverage our discrete controller synthesis algorithms, which are designed to be highly suitable for the problem at hand. Through this approach, we generate a controller that serves to ensure safety by satisfying shared resource constraints, all while concurrently enabling energy minimization. Our symbolic limited optimal discrete control algorithm plays a pivotal role in achieving this balance.

With a focus on resource restrictions and energy optimization, this methodology is specifically designed for the discrete control synthesis problem and offers an efficient framework for addressing complicated control and optimization challenges.

Modeling of Tokens:

As seen in Figure 2, our token model is effectively represented as a Mealy machine. Tokens are generated or consumed with each discrete event or atomic operation in this architecture when states transition. To mimic this traffic, we use unbounded FIFOs, which enable tokens to move smoothly between states.

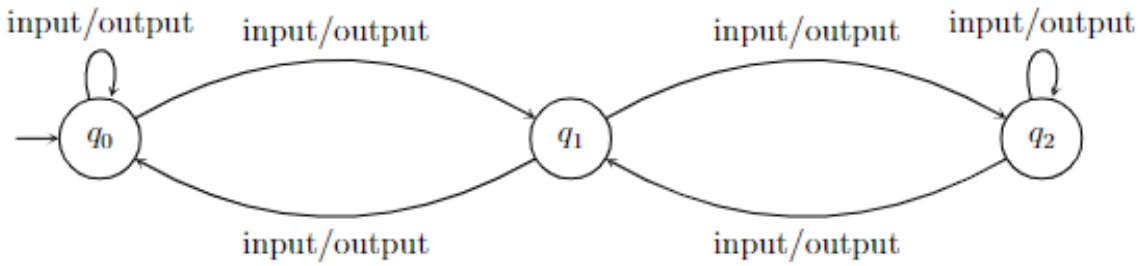

Figure 2. ***Generic Modeling of Tokens***

Term definitions like "empty", "middle", and "high" serve as examples of the states. Transitions between these well crafted states happen in response to the dynamic token generation and consumption processes, and they represent the many levels of tokens that exist within the system. This Mealy machine ensures the system's responsive and effective functioning by providing a strong foundation for recording and overseeing token-based interactions.

Modeling of Processes:

Our processes can carry out the same task with many configurations or functionalities, as shown in Figure 3. It's crucial to remember that tokens flow along the edges, signifying the creation and usage of tokens by various operations.

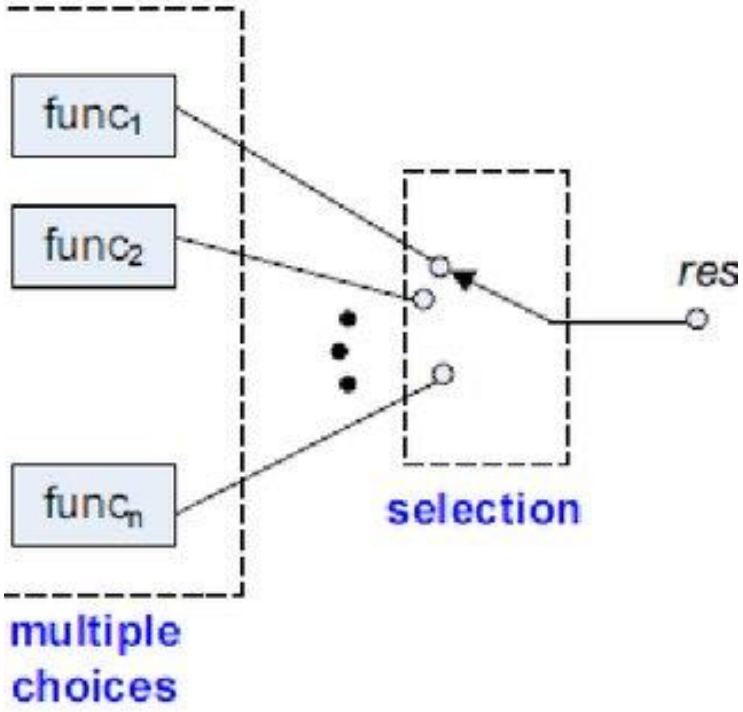

Figure 3. ***Generic Modeling of Process***

In contrast, each process's current state is represented by the state variable, whose value depends on the configuration options that are accessible. The controller plays a pivotal role in selecting the appropriate configuration based on the last consumed data by the process.

Consequently, our process model effectively preserves system behavior while simultaneously facilitating the optimization of the desired objectives. This approach ensures that the system remains flexible, adapting to various requirements by selecting the most suitable configurations, all while maintaining its overall integrity and performance.

System Control:

In the context we are addressing, we have two distinct control objectives. The first objective revolves around safety, focusing on the management of shared resources, while the second objective pertains to symbolic limited optimal control, with an emphasis on the minimization of energy consumption.

Building upon the aforementioned models, we encode the discrete control problem as synchronous parallel dataflow equations. Subsequently, we employ our relevant synthesis algorithms to generate a controller. This controller, in turn, assumes the role of a “power-aware reconfiguration manager”.

This meticulous approach aligns with our overarching goals. It allows us to ensure the safety of operations through resource allocation and concurrent resource sharing, while also striving to optimize energy utilization. The dual nature of our control objectives reflects our commitment to achieving both system reliability and energy efficiency within the dynamic context of the reconfigurable system.

Findings and Discussion

Initially, we applied our methodology to an artificial scenario, modeling it as dataflow equations in the ReaX environment. Subsequently, we facilitated controller synthesis using our tailored synthesis algorithms. Additionally, we implemented the Python environment to observe results, developing both the environment and incorporating the generated controller into the Python setup.

Our evaluation was conducted from two distinct perspectives. First, we randomly selected scenarios from various design processes. Second, we evaluated the selections made by our manager, which our approach produced. The results indicate an average savings of approximately 20%.

These findings underscore the effectiveness of our methodology in optimizing system performance. The application of our approach to diverse design processes and the manager selections has consistently yielded substantial efficiency improvements.

Conclusion and Recommendations

In this study, we systematically introduced the creation of an energy-efficient system manager for smartphones, employing a systematic framework and symbolic discrete control synthesis methodology. Our approach effectively addresses both shared resource constraints and energy optimization within the discrete controller synthesis technique through the utilization of optimization and safety algorithms. Furthermore, our modeling choice, the Kahn Process Network, demonstrates its effectiveness in capturing the dynamics of such systems. Our practical applications showcase the efficacy of our approach in practice. It is worth noting that in future work, considering multicriteria objectives will likely lead to even more favorable outcomes. This approach promises to yield superior results by simultaneously optimizing multiple critical aspects of the system's performance.

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PREDICTIVE MAINTENANCE APPLICATION ON PIPELINES USING ARTIFICIAL INTELLIGENCE MODEL

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ABSTRACT

Recent incidents of pipeline losses and leaks pose substantial economic and environmental challenges, necessitating proactive measures for early fault detection and diagnosis. This research explores the application of predictive maintenance through the Support Vector Machine (SVM) method to address potential pipeline fault scenarios. While the Magnetic Flux Leakage (MFL) method is currently prevalent for fault detection, it is also widely employed as a non-destructive testing technique to identify defects in pipe walls. Identified fault conditions are subjected to thorough analysis through image processing. To gather pertinent data, experimental techniques employing pressure sensors were employed in this study. Data sets were meticulously generated from the collected information, and an SVM artificial intelligence model was subsequently deployed to these sets. SVM, a well-established supervised learning method for classification tasks, establishes an optimal separation line for points on a plane, maximizing the distance from points of both classes. This strategic approach enables the detection of faults before they materialize, aligning seamlessly with the principles of predictive maintenance. The underlying hypothesis of this study asserts that the SVM model can effectively implement predictive maintenance in the face of pipeline failures. Proactively preventing malfunctions in pipelines is deemed a crucial step in conserving liquid and gas resources, encompassing water, natural gas, and oil transported through pipelines, thereby contributing to the overall safeguarding of the environment.

Keywords: Pipelines, Artificial Intelligence, Predictive Maintenance

1. Introduction

1.1.Objective

Predictive maintenance entails the continuous monitoring of the conditions of equipment and components, coupled with the evaluation of data through analytical methods, with the objective of early detection of potential faults. This method is utilized to anticipate breakdown risks and optimize system performance by implementing effective preventive measures. The aim of this experiment is to focus on the early diagnosis and detection of faults in pipelines, particularly by exploring the applicability of predictive maintenance using the Support Vector Machine (SVM) method. The study's objective is not only to reduce economic costs but also to contribute significantly to environmental conservation. Currently, pipeline losses and leaks pose substantial economic and environmental challenges. This research aims to address these issues by thoroughly examining how predictive maintenance, conducted through the SVM method, can contribute to resolving these problems. The overarching goal of the article is to highlight the potential of SVM-based predictive maintenance as an effective method to enhance efficiency in industrial processes, promote the sustainable use of energy resources, and enable early detection of potential faults in pipelines. In this context, the study's outcomes aspire to shed light on practical applications that could positively impact the reliability and sustainability of pipelines.

1.2. Materials and Methods

Following a literature review, we observed the widely used Magnetic Flux Leakage (MFL) method for detecting faults in pipelines. MFL is recognized as a highly effective non-destructive examination method for

identifying defects in pipe walls. The primary focus of this study is to outline the materials and methods employed to obtain and analyze experimental data. In our investigation, pressure sensors were utilized to achieve the research objectives. The data obtained through these sensors were used to create various datasets. Subsequently, the Support Vector Machines (SVM) artificial intelligence model was applied to these generated datasets. SVM is a supervised learning method commonly used for classification problems. This model draws a line on a plane to separate points and aims to maximize the distance between this line and points from both classes. The use of Support Vector Machines allows for the early detection of faults in line with the philosophy of predictive maintenance, where the goal is to identify issues before they manifest. This methodology is crucial for the early diagnosis of faults in pipelines and the effective implementation of preventive maintenance. The Materials and Methods section of the study provides a detailed explanation of the techniques and processes used to apply this new and effective method.

2. Findings and Discussion

In this article, we will delve into detailed studies conducted on the experimental setup. Figure 1 illustrates the experimental setup employed in the study. The experimental setup includes necessary resources for conducting both gas and liquid experiments in the lower section. An electric motor facilitating the introduction of water into the system from the liquid tank and a compressor pumping gas into the system from the gas tank are present. Flowmeters are utilized in both systems for flow rate measurements. Prior to experiments and scenarios, the system is operated until it reaches a stable state, and the drain valve at the top is kept open before introducing any input to the system. Additionally, spherical valves causing blockages within the system, one-way valves, hose connection elements used to simulate drainages and leakage faults, and on-off valves for each channel are present. For each scenario, faults are introduced through hoses connected to the output sections, and the other ends of the hoses are connected to sensors. These sensors measure pressure values and transmit them to the electrical panel as voltage values. Voltage values are then converted to current values through converters and transferred to the data module.

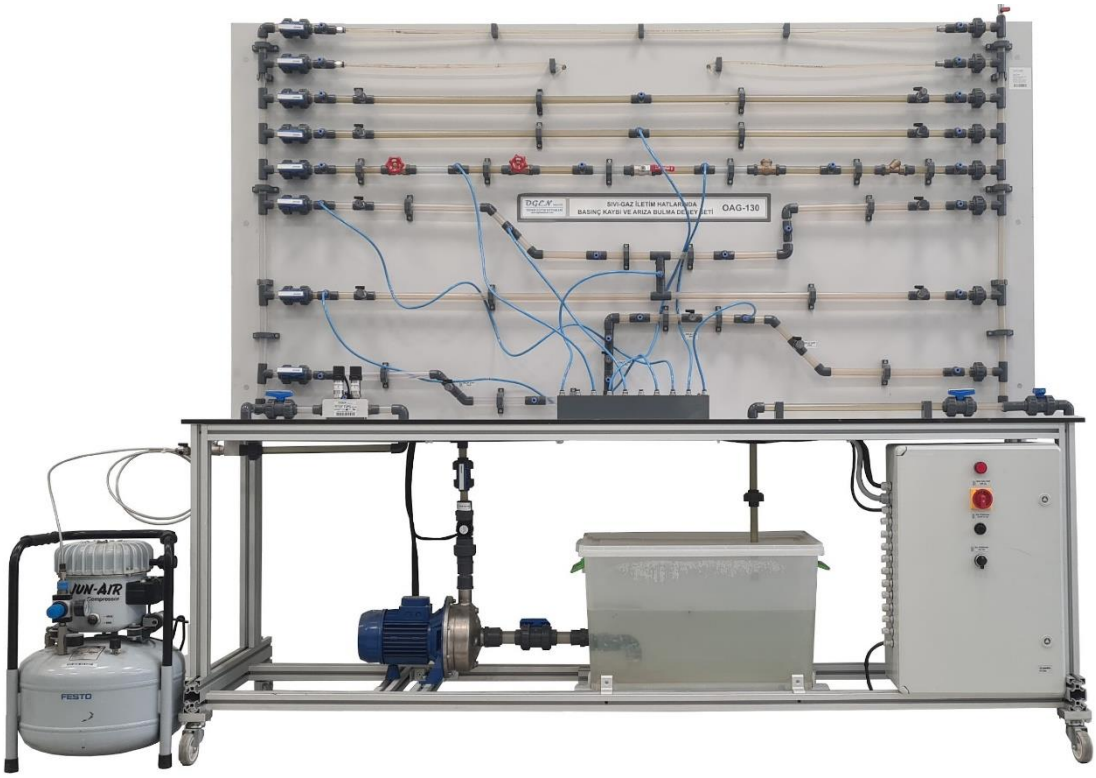


Figure 1- General View of Experiment Set

Figure 2- Electric Cabinet

Figure 3- Pump

Figure 4- Data Acquisition Module

Figure 5- Speed Control for Pump

Figure 6- Power Module

Figure 7- Fuse Switch

During the experiments, diagrams designed and drawn for each scenario were utilized. Below is a visual example of one of the eight scenarios we experienced. The diagrams assigned to each scenario served as guides during the experiments, facilitating a better understanding of the conducted experiments. The aim of these experimental studies is to comprehend potential faults that may arise in the specified scenarios and evaluate the performance of the system.

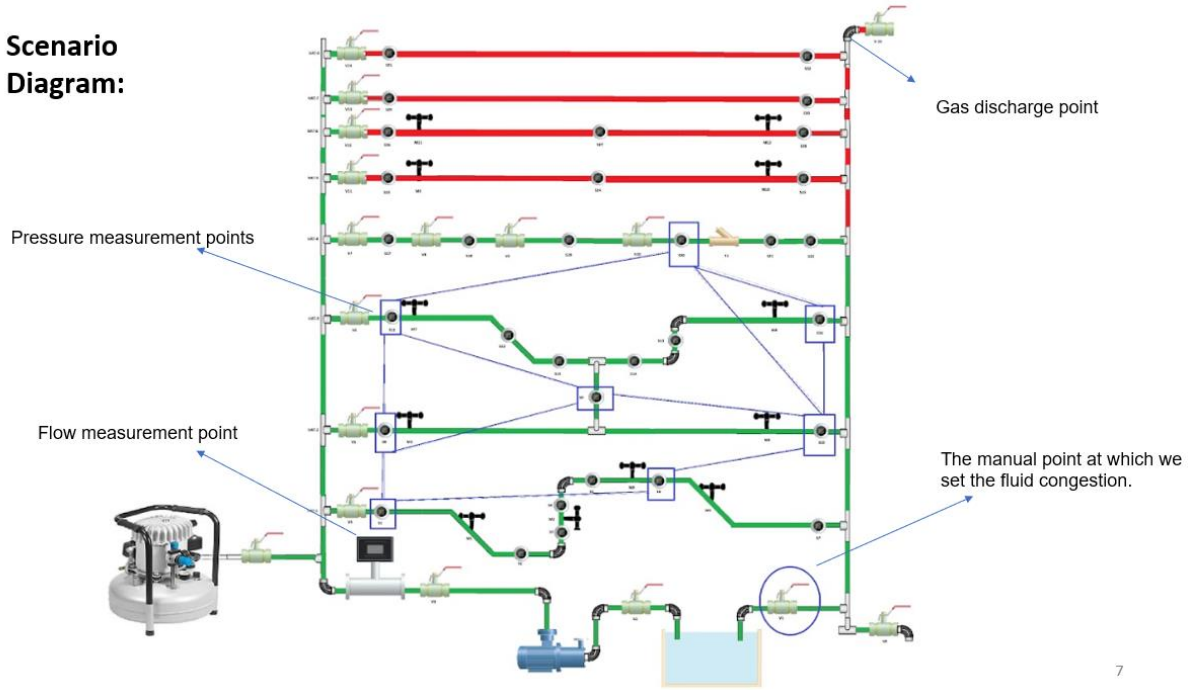


Figure 8 – Clogging 1, Scenario Diagram

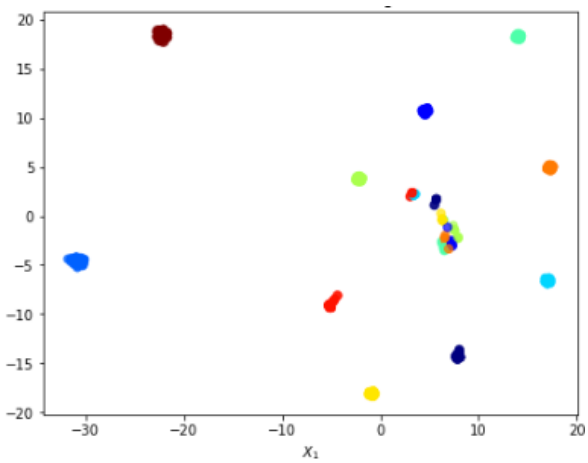
In this article, we will focus on the details of an experiment conducted in a system that includes both open and closed channels. Open channels are represented in green, while closed channels are indicated in red. The system under examination pertains to a scenario named "Blockage 1." The virtual representation of this scenario includes measurement points, pressure measurement points, gas vent points, and manual points. Additionally, details of the measurement values obtained from the 8 points enclosed in squares will be shared in the Findings and Discussion section. This scenario is specifically designed to understand the interactions between open and closed channels and evaluate the system's performance, given that it simulates a blockage condition in the system. The experiment details, measurement values obtained, and their analysis will be comprehensively addressed in the Findings and Discussion section, assessing the impacts on the system's stability, efficiency, and durability. This study aims to contribute significantly by understanding the effects of the blockage scenario on the system and providing insights into potential solutions.

3. Conclusion and Recommendations

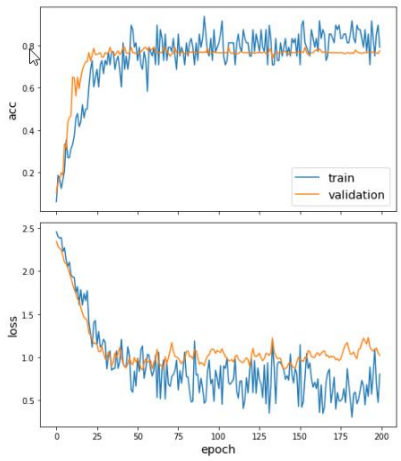
X_Value	AI Channel 0	AI Channel 2	AI Channel 3	AI Channel 4	AI Channel 6	AI Channel 7	AI Channel 8	AI Channel 9
0	9.999694824	9.54864502	9.999694824	9.764404297	9.999694824	9.999694824	8.56628418	9.999694824
0.1	9.999694824	9.562683106	9.999694824	9.75982666	9.999694824	9.999694824	8.55255127	9.999694824
0.2	9.999694824	9.566345215	9.999694824	9.778137207	9.999694824	9.999694824	8.561401367	9.999694824
0.3	9.999694824	9.579162598	9.999694824	9.796447754	9.999694824	9.999694824	8.576354981	9.999694824
0.4	9.999694824	9.53704834	9.999694824	9.775085449	9.999694824	9.999694824	8.575134277	9.999694824
0.5	9.999694824	9.573059082	9.999694824	9.774475098	9.999694824	9.999694824	8.56048584	9.999694824
0.6	9.999694824	9.567871094	9.999694824	9.77355957	9.999694824	9.999694824	8.576965332	9.999694824
0.7	9.999694824	9.560852051	9.999694824	9.767761231	9.999694824	9.999694824	8.580627441	9.999694824
0.8	9.999694824	9.557189941	9.999694824	9.778137207	9.999694824	9.999694824	8.574523926	9.999694824
0.9	9.999694824	9.559631348	9.999694824	9.801635742	9.999694824	9.999694824	8.565368652	9.999694824
1	9.999694824	9.558410645	9.999694824	9.753723145	9.999694824	9.999694824	8.571166992	9.999694824
1.1	9.999694824	9.523620606	9.999694824	9.777526856	9.999694824	9.999694824	8.570251465	9.999694824
1.2	9.999694824	9.578857422	9.999694824	9.76348877	9.999694824	9.999694824	8.56842041	9.999694824
1.3	9.999694824	9.539794922	9.999694824	9.783630371	9.999694824	9.999694824	8.559265137	9.999694824
1.4	9.999694824	9.557800293	9.999694824	9.780883789	9.999694824	9.999694824	8.565979004	9.999694824
1.5	9.999694824	9.554748535	9.999694824	9.777832031	9.999694824	9.999694824	8.562927246	9.999694824
1.6	9.999694824	9.578552246	9.999694824	9.765930176	9.999694824	9.999694824	8.570861816	9.999694824
1.7	9.999694824	9.553527832	9.999694824	9.779968262	9.999694824	9.999694824	8.58001709	9.999694824
1.8	9.999694824	9.539489746	9.999694824	9.757995606	9.999694824	9.999694824	8.565063477	9.999694824
1.9	9.999694824	9.526672363	9.999694824	9.782409668	9.999694824	9.999694824	8.557128906	9.999694824
2	9.999694824	9.578552246	9.999694824	9.775085449	9.999694824	9.999694824	8.558349609	9.999694824
2.1	9.999694824	9.582214356	9.999694824	9.764099121	9.999694824	9.999694824	8.56842041	9.999694824
2.2	9.999694824	9.553833008	9.999694824	9.763183594	9.999694824	9.999694824	8.558654785	9.999694824

Table 1 - Values obtained as a result of the experiment.

In this study, the variable X represents real-time timestamp values. The data obtained from sensors in AI Channels 0, 2, 3, 4, 6, 7, 8, 9 used in our analyses include pressure values. These pressure values constitute the equivalents of the current values processed by the converter. In our future studies, a framework will be established to evaluate the model's performance and present the results obtained in the full text. Visual tools such as accuracy loss graphs, confusion matrices, and ROC curves will be employed when examining the model's results. Additionally, metrics such as F1 score, precision, recall, and accuracy will be used to objectively assess the model's performance. Based on the obtained performances, optimization processes will be conducted through model parameters. These optimizations will enhance the model's efficiency and reliability. Independent error scenarios were run for each dataset, and data were obtained based on these scenarios. The analyses conducted using the SVM model demonstrate the feasibility of predictive maintenance in pipeline fault situations.



Graphic 1- Core Dataset View



Graphic 2- Taught and Tested Evaluation

These findings indicate the need for a more in-depth examination of the model's performance and the continuation of analyses. Consequently, the results obtained shed light on the successes of the model and form a significant foundation for future studies. This research provides a valuable contribution to the effective implementation of predictive maintenance in industrial processes.

4.Thanks and Information Note

I extend sincere gratitude to my esteemed mentors, Assistant Professor İsmail TEMİZ and Professor Mustafa Caner AKÜNER, for their invaluable guidance and mentorship in steering this research on predictive maintenance in pipelines. I am deeply thankful to my supportive wife, Natalya ALIN, our bright son, Leon ALIN, and my partner, Ersin ŞAHİN, whose unwavering encouragement has fuelled my passion for research. A heartfelt appreciation goes to my parents, Melek ALIN and Zeki ALIN, for their enduring belief in my abilities. This research stands as a testament to the collective efforts of these exceptional individuals, and I am profoundly grateful for their contributions and unwavering support throughout this transformative journey.

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FRICTION LOSS GENERATED IN MULTILOBE AND TILTING –PAD

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ABSTRACT

The multilobe or tilting-pad journal bearings show good cooling conditions, good damping of vibrations and the stability during operation and they are mostly used in high-speed rotating machines These bearing are applied, e.g. in the spindle systems of grinding machines that applies the 3-, 4-, 6- and 8- lobe fixed lobes or in the steam and gas turbines, turbo-compressors and turbine gearboxes. As compare to the cylindrical journal bearings, the multilobe bearings with fixed segments or tilting-pads show higher friction loss. One of the advantages of the tilting-pad journal bearings consists in a progressive increase of assembly stiffness with geometric preload. However, some disadvantages of these types of bearings include a higher friction and lower load capacity than the multilobe ones.

This paper considers the friction loss in multilobe and tilting-pad journal bearings applied in different branches of industry, e.g. in the bearing system of grinding machine and large overall dimensions bearings of water turbines. The friction loss expressed by the friction force was obtained from numerical solution of Reynolds, energy, geometry and viscosity equations. Incompressible lubricant, laminar and adiabatic flow of oil in the bearing gap of finite length bearing were assumed. Aligned orientation of bearing and journal axis without deflections of bearing and journal or tilting-pads was assumed. Calculations were performed on the conditions of the static equilibrium position of journal.

Keywords: multilobe, tilting-pad journal bearings, friction force.

Introduction

Development of high speed, very efficient rotating machinery depends on the applied journal bearings systems. One of the factors affecting robust, very efficient and energy saving design of machine operation is the friction. It should be very useful to compute and analyse the bearings from the point of loss caused by friction in the tribopair journal-oil film-sleeve. Energy savings in rotating machinery are of great deal for the environment and operational costs. The knowledge of the parameters affecting the friction in the bearings systems becomes more and more important, particularly in large-overall dimensions rotating machinery. Reliable and durable operation of responsible rotating machinery depends on the sophisticated and adequate process of the computation of journal bearing and bearing system (Pinkus, 1990, Someya, Strzelecki, 196, Strzelecki, 2021). The developed numerical algorithms allow determination the bearing characteristics and it includes among others the friction force and the stability of rotor operating in assumed type of bearings. They provide the necessary data for manufacturing the bearings that have to be precisely machined in order to obtain maximum life and reliability.

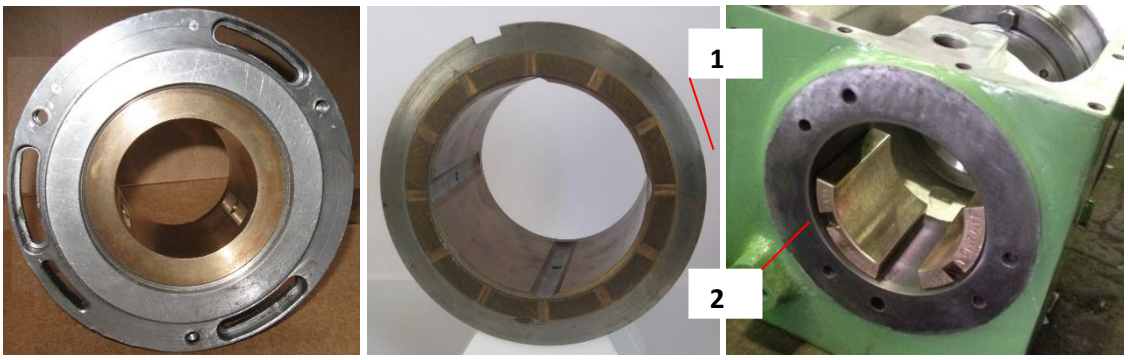
Performance characteristics of journal bearings include the static and dynamic characteristics as well as the stability of rotor computed on the assumption of adiabatic or diathermal laminar or turbulent oil film. Static characteristics of journal bearing comprise the oil film pressure, temperature, viscosity distributions, static equilibrium position angles, Sommerfeld number (dimensionless load capacity), minimum oil film thickness, maximum oil film temperature, oil flow, friction force (Strzelecki 2021, Han 1979).

The design solutions of the spindle systems of grinding machines apply the 3-, 4-, 6- and 8-lobe journal bearings. Such bearings are manufactured as the bearings with cylindrical lobes of non-continuous sleeve profile separated by respective number of oil grooves (Pinkus 1990, Someya, Strzelecki, 1996), or the bearings with the continuous pericycloid ("wave") profile of bearing bore (Strzelecki, Socha 2010, Dimofte, 1995; Strzelecki, 2021). All types of above mentioned bearings have the lubricating grooves arranged uniformly every 120^0, 90^0, 60^0 or 45^0 on the bearing peripheral. An example of such bearings

application is the bearing system of the spindle of grinding machine (Strzelecki, Socha, 2010). In case of grinding machines the most important feature is very high preciseness of grinding operation. It requires of the highest preciseness of spindle bearing system. Correctly chosen and designed journal bearings assure lower friction, proper cooling conditions and generate less heat that could effect the deformation of machine. The proper choice of geometric, design and exploitation parameters of bearings assures the failure free, reliable operation of grinding machine at proper thermal conditions and low friction.

Another industrial application of multilobe journal bearings is a planetary gearbox of ultrasonic compressor (Strzelecki, 2021). The output central shaft of such gearbox operates in compact axial thrust - radial (4-lobe) and in radial 4-lobe journal bearing at the rotational speed about 18000 rpm and the satellite gears rotate on the 4-lobe stationary journals (Strzelecki, 2021).

The multilobe journal bearings applied in grinding machines shows Fig. 1; thick wall housing contains the 3-lobe journal bearing with the pericycloid profile of bore (Fig. 1a). Figure 1b shows axial thrust - radial bearing with the radial part as 4-lobe bearing. In some design solutions of spindle stock of these machines the bearings with the tilting-pads are applied, too (Fig. 1c).



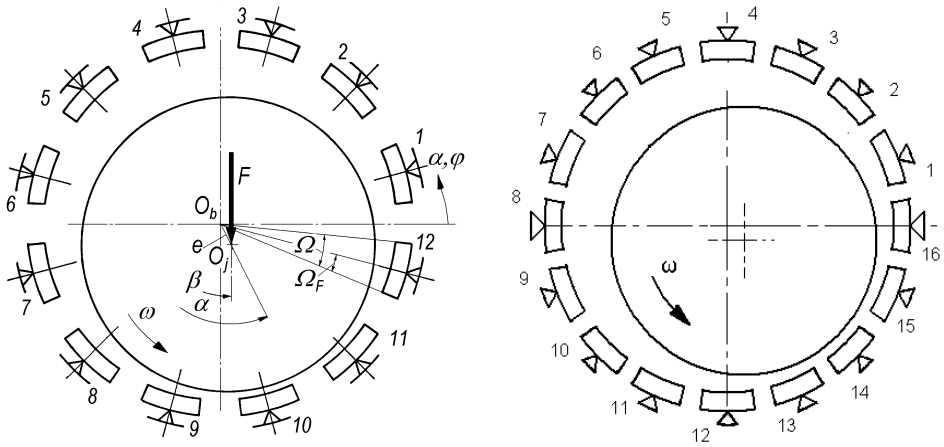
a) b)

c)

Figure 1. Examples of 3- and 4-lobe journal bearings design: a) – view of the thick-wall housing with 3-lobe radial journal bearing of the nominal diameter Ø 79 mm, b) – view of cast, thin bronze layer 4 – lobe axial-radial journal bearing of grinder spindle (nominal bore diameter Ø 90 mm, c) – spindle stock with tilting 3-pad journal bearing; 1 – housing, 2 – tilting pad

The bearing systems of the hydropower generating units consist the tilting 12- or 16-pad large overall dimensions radial bearings (Fig. 2), which are guiding (stabilizing) the vertical rotor of turbine (Strzelecki, Brito 2008, Strzelecki, Spałek 2001),. These bearings assure the stable operation of rotor at the speed, e.g. 92 rpm that is required by water turbine. Large number of pads allows good cooling of bearing too. Technical data of ITAIPU hydro power plant, large overall dimensions tilting-pad bearing of hydro turbine gives Table 1.

The layout of tilting 12- and 16-pad journal bearings shows Fig. 2; the case of the bearing with the load applied between pads (LBP) is given in Fig. 2a, and the case with the load on pad (LOP) gives Fig. 2b. Such arrangement of bearing pads causes that there are different bearings static and dynamic characteristics (Klumpp 1975, Strzelecki 2004, Strzelecki, Someya, 2002, Strzelecki, Ghoneam 2003).



a) b)

Figure 2. Tilting 12- and 16-pad journal bearings: a) load on pad (LBP), b) load between pads (LOP)

Table 1. Technical data of ITAIPU hydro power plant turbine bearing

Symbol	Description	Unit	Value
n_p	Number of pads	unit	16
r	Shaft radius	mm	2600
R	Pad radius	mm	2604
n	Rotating speed (50/60 Hz units)	rpm	90.9/92.3
c_0	Nominal clearance (cold)	mm	0.950
αR	Distance from pivot point to the oil output	mm	248
βR	Pad length	mm	620
L	Pad width	mm	310

This paper considers the friction loss that is given by friction force of multilobe and tilting-pad journal bearings. Two examples of friction generated in industrial application, such as the bearing system of grinding machine and large overall dimensions tilting-pad bearings of water turbines were considered. On the assumptions of the thermo hydrodynamic theory of lubrication the friction force of such bearings was obtained. The condition of static equilibrium position of journal was assumed in calculation.

Bearings geometry

The geometry of the oil film gap of multilobe journal bearings (Fig. 3) describes equation (1).

$$\overline{H}(\varphi) = \overline{H}_{Li}(\varphi) - \varepsilon\cos(\varphi - \alpha) \tag{1}$$

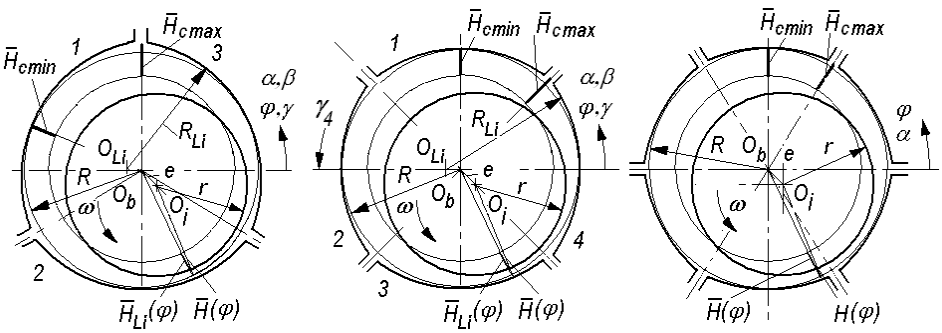
where: $\overline{H}(\varphi)$ – dimensionless oil film thickness ($\overline{H} = h/\Delta R$), h – oil film thickness (m), $\Delta R = R - r$, radial clearance (m), r, R – journal and bearing bore radius (m), α – attitude angle, (^{0}), ε – relative eccentricity $\varepsilon = e/\Delta R$, e – journal eccentricity (m), φ – peripheral co-ordinate, (^{0}).

The first term of the right side of Eqn. (1), i.e. $\overline{H}_{Li}(\varphi)$, determines the gap geometry of multilobe journal bearings at the concentric position of journal and bearing axes and it has the following form:

$$\overline{H}_{Li}(\varphi) = \psi_{si} + (\psi_{si} - 1)\cos(\varphi - \gamma_i) \tag{2}$$

where: γ_i – angle of lobe centre point, (^{0}), ψ_{si} – lobe relative clearance.

Exemplary, in case of 4-lobe journal bearing, the angle γ_i is placed opposite to the respective lobe, e.g. $\gamma_4 = 180^0$ for the lobe No 4 (Fig. 3b).



a) b)

c)

Figure 3. Geometry of 3-, 4 - , and 6 -lobe journal bearings; a- 3 - lobe, b - 4-lobe, c - 6-lobe journal bearing, e.g. γ_4-angle of lobe No 4 centre point, O_{Li}, and R_{Li} correspond respectively to O_4 and R_{L4}, O_b, O_j, O_L centre of bearing, journal and lobe $\bar{H}_{C\,\min}$, $\bar{H}_{C\,\max}$ -minimum and maximum value of oil gap at concentric position of journal and bearing axis

Geometry of lubricating gap of tilting pad journal bearing that is determined by Eqn. (3) depends on the lobe relative clearance ψ_s , the angle τ_o of lobe centre line at stationary state and it is decided by angular orientation τ_1 of the centre point of pad (Klumpp 1975). During computation of the static equilibrium position of pad, the angle τ_1 should be varied as long as the magnitude of lubricating gap allows the oil film pressure distribution that gives the resultant force to go through the support point of pad (Strzelecki 2021).

$$\bar{H}(\varphi) = \psi_s + \frac{\psi_s - 1}{\cos(\tau_1 - \tau_o)} \cdot \cos(\varphi - \tau_1) - \varepsilon \cdot \cos(\varphi - \alpha) \tag{3}$$

Numerical solution of the equations of thermo-hydrodynamic theory of lubrication gives the necessary data on the static characteristics (Pinkus 1990, Strzelecki 2021) that are the input variables for the design of bearing, calculations of its static and dynamic characteristics and the determination of rotor stability.

The basic equations in the calculations of bearing characteristics are the geometry, Reynolds', energy and viscosity equations (Strzelecki 2021, Strzelecki, Someya 2002). These equations were obtained on the assumption that in the bearing gap exists the adiabatic laminar flow of non-compressible Newtonian fluid. The numerical algorithm applied in the calculations of friction forces gives reasonable results that can be applied for the analysis of power savings in the journal bearings.

The oil film pressure distribution was calculated from the Reynolds equation (4)

$$\frac{\partial}{\partial \varphi}\left(\frac{\bar{H}^3}{\bar{\eta}}\frac{\partial \bar{p}}{\partial \varphi}\right) + \left(\frac{D}{L}\right)^2 \frac{\partial}{\partial \bar{z}}\left(\frac{\bar{H}^3}{\bar{\eta}}\frac{\partial \bar{p}}{\partial \bar{z}}\right) = 6\frac{\partial \bar{H}}{\partial \varphi} + 12\frac{\partial \bar{H}}{\partial \phi} \tag{4}$$

where: D, L -bearing diameter and length (m), $\bar{p}$ - dimensionless oil film pressure, $\bar{p} = p \cdot \psi^2 / \eta \cdot \omega$, $\boldsymbol{p}$ - oil film pressure, (MPa), $\bar{\eta}$ -dimensionless viscosity of oil, $\bar{\eta} = \eta$ / η_o,), η -dynamic viscosity of oil, (Ns/m^2 η_o- dynamic viscosity at ambient temperature (Ns/m^2), ω- angular velocity (s^{-1}),

Dimensionless form of energy equation that was applied in this paper is:

$$\frac{\partial \bar{T}}{\partial \varphi} = \eta K_T \left(\frac{\partial \bar{u}}{\partial \bar{y}}\right)^2 + \frac{1}{Pe}\frac{\partial^2 \bar{T}}{\partial \bar{y}^2} \tag{5}$$

where: K_T - heat number, $K_T = \omega \cdot \eta_0 / c \cdot \rho \cdot T_0 \cdot \psi^2$, $\bar{T}$ – dimensionless temperature of oil film, T_0 – supplied oil temperature, c-specific heat capacity, (J/kgK), ρ – oil density (kg/dm^3), Pe – Peclet number $Pe = \rho c \omega r^2 / h$, r, $\bar{u}$ – dimensionless velocity in peripheral direction $\bar{u} = u/\omega r$, $\bar{y}$ – dimensionless coordinate of oil film thickness $\bar{y} = y/h$.

Velocity distribution in the oil film thickness was obtained from

$$\bar{\eta}\frac{\partial^2 \bar{u}}{\partial \bar{y}^2} + \frac{\partial \bar{\eta}}{\partial \bar{y}}\frac{\partial \bar{u}}{\partial \bar{y}} = 0 \tag{6}$$

Oil film pressure, temperature and viscosity fields were obtained by numerical solution of equation (4) together with energy equation (5). The pressure boundary condition assumes the positive values of oil film pressure only and the ambient pressure on the sides of bearing. The oil film temperature $\bar{T}(\varphi, \bar{z})$ on the bearing edges ($\bar{z} = \pm 1$) was computed by means of parabolic approximation. The boundary conditions for the oil film pressure and temperature include the value of inlet oil pressure and temperature. The viscosity of oil was described by the exponential equation (Strzelecki 2021, Strzelecki 2002, Strzelecki, Kapusta 2004).

Dimensionless friction force F_r expresses the equation (7). It consists the term that results from the offset between the centre of the shaft and that of the bearing and the second term is the simple Newton friction.

$$F_r = -\frac{1}{4}\int_{-1}^{+1}\int_{0}^{2\pi}\left[\frac{\bar{H}}{2}\frac{\partial \bar{p}}{\partial \varphi} + \frac{\bar{\eta}}{\bar{H}}\right] d\varphi d\bar{z} \tag{7}$$

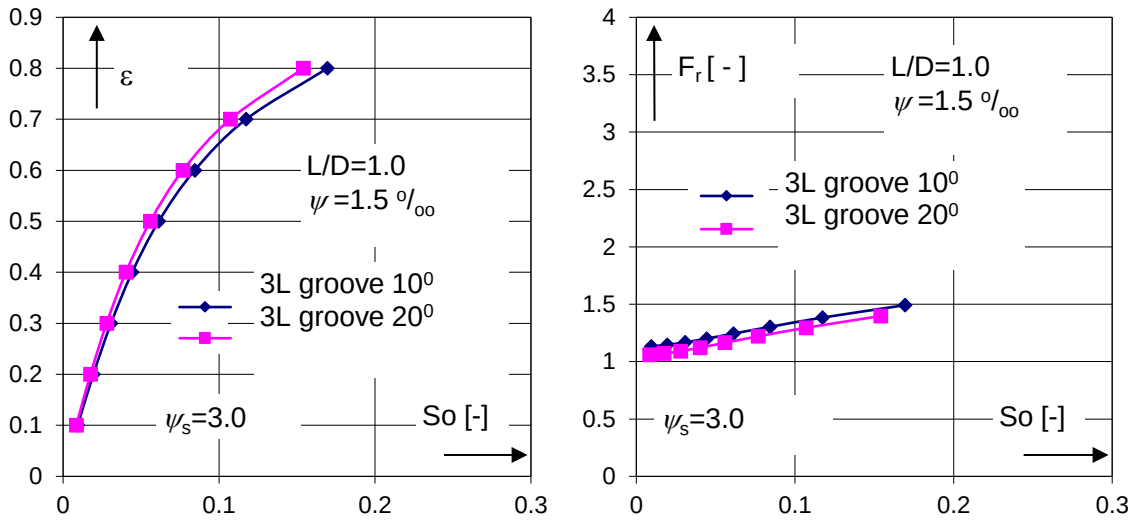
The integrated oil forces on the shaft and bearing act through their respective centres, which are, in the direction of the load, a distance apart and there will be a couple sets up of magnitude, which corresponds to a friction force at the surface of the shaft (Strzelecki 2009).

Equation (7) was applied in the developed program of numerical calculations of friction force of considered bearings. No elasticity and friction of pad supports as well as the mass of pad were considered.

Friction of multilobe journal bearings

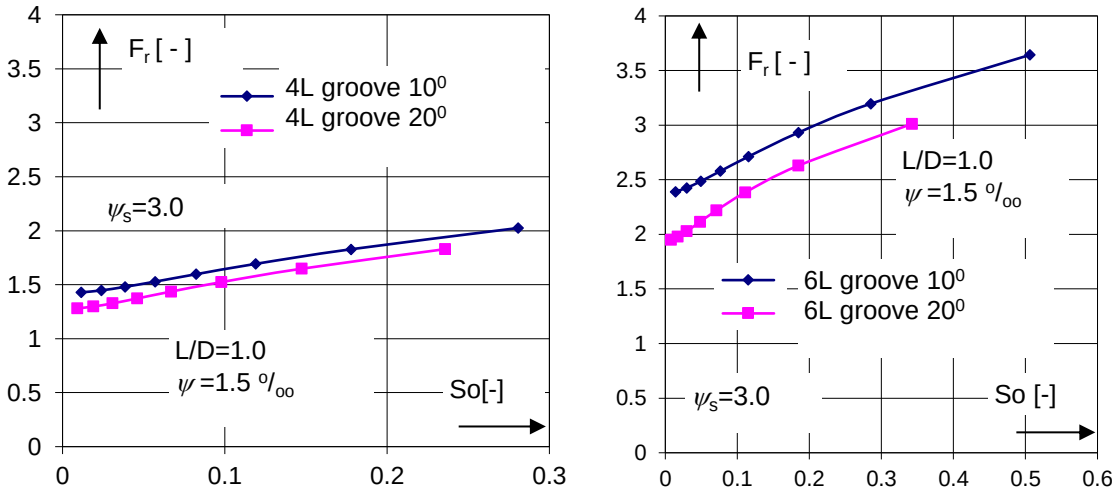
The numerical algorithm (Strzelecki 2021, Strzelecki 2009) was applied for obtaining the performances of multilobe or tilting-pad journal bearings with laminar, adiabatic oil film. Different values of bearing length to diameter ratio L/D, bearing relative clearance ψ and the lobe relative clearance ψ_s were assumed. The values of heat number K_T were calculated on the basis of assumed bearing relative clearances.

The oil grooves, their dimensions and profile affect the bearing operation. An effect of oil grooves on the journal displacements and friction force of 3-, 4-, and 6-lobe bearings show Fig. 4 through Fig. 6. An increase in the oil groove width causes the increase in the journal displacements (Fig. 4a) at assumed Sommerfeld number ($So = F \cdot \psi^2 / (L \cdot D \cdot \eta \cdot \omega)$, F - resultant force of oil film (N)), but it causes the decrease in the friction force (e.g. Fig. 4b and Fig. 5a,b). At the increase in the lobe number there are larger differences in friction force at the increase in the oil groove width (e.g. Fig. 4b and Fig. 5b).



a) b)

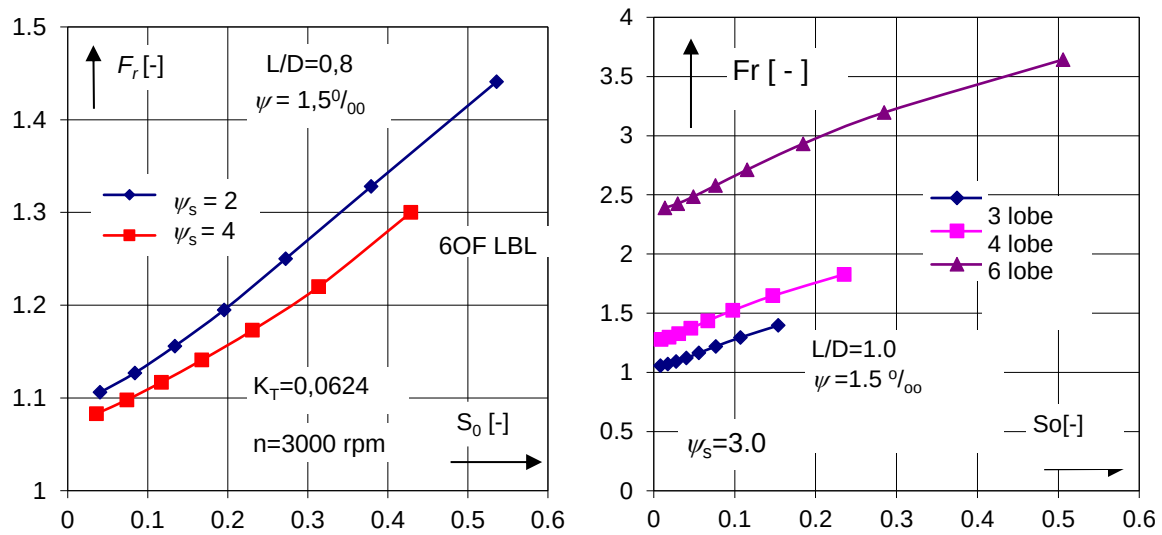
Figure 4. Journal relative eccentricity (a) and friction force (b) of 3-lobe journal bearings versus Sommerfeld number for different width of oil grooves



a) b)

Figure 5. Friction force of 4-lobe journal (a) and 6-lobe (b) journal bearing versus Sommerfeld number at different oil grooves width

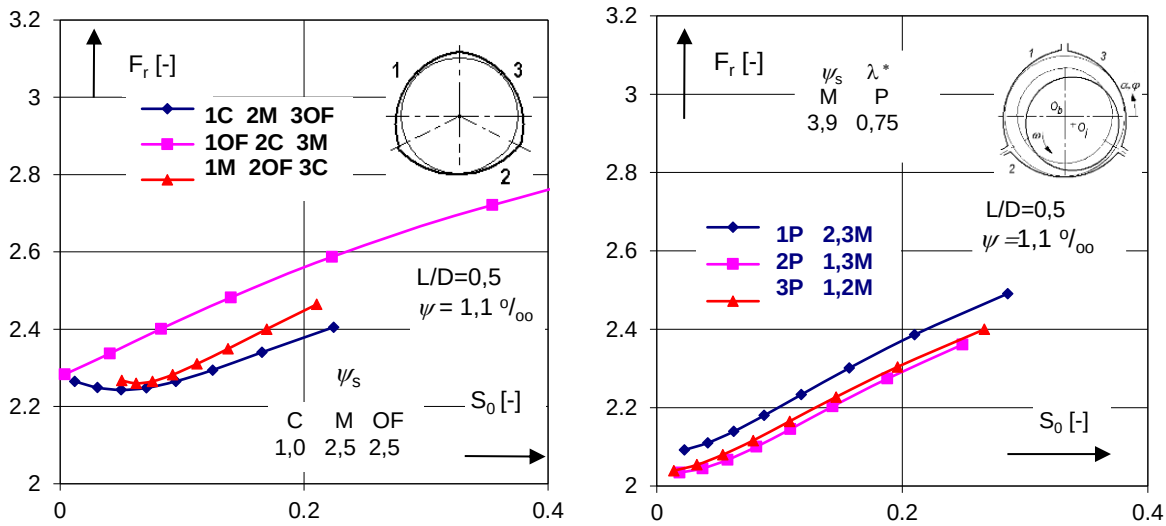
Larger number of operating lobes at causes better cooling conditions in oil film and it gives lower temperatures. As a result there is an increase in the bearing load capacity So and in the friction force The variations of friction force F_r at different values of lobe relative clearance ψ_s and different number of lobes versus Sommerfeld number *So* gives Fig. 6; an increase in lobe relative clearance causes the decrease in friction force (Fig. 6a for 6-lobe Offset bearing). Figure 6b shows an increase in friction force at the increase in the number of lobes.



a) b)

Figure 6. Effect of lobe relative clearance on the friction force of 6-lobe journal at different bearing relative clearance (a) and for different types of multilobe bearings

A multilobe journal bearing may be designed with the lobes of the same or different geometry (Strzelecki 2021). Classic multilobe bearings have all lobes of a circular profile. An effect of the lobes of different geometry (LDG) bearings on the friction force shows Fig. 7.



a) b)

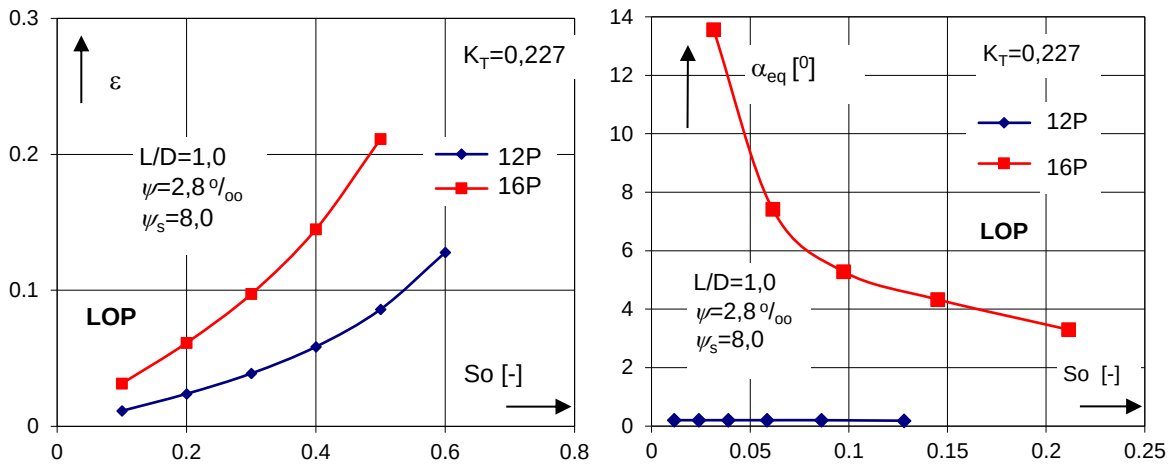
Figure 7. Effect of the lobe of different geometry on the friction force of 3-lobe journal bearings versus Sommerfeld number; C – cylindrical, M – multilobe, OF – Offset, P – pericycloid (λ* - relative eccentricity of pericycloid – Strzelecki 2021)

Friction of tilting-pad journal bearing

The calculations have been performed based on the technical data of tilting 12- and 16-pad journal bearings of hydro power plant units Strzelecki, Brito 2008). Oil dynamic viscosity η and lubricant specific mass ρ were respectively 0,047 Ns/m^2 and 873 kg/m^3.

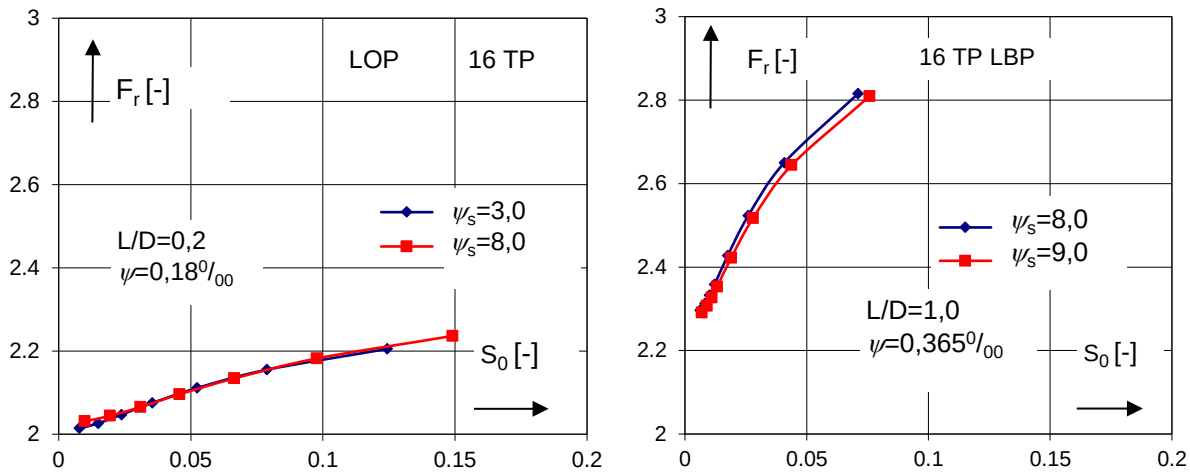
At assumed Sommerfeld number there is larger displacement of journal for tilting 16-pad journal bearing than for the 12- pad one (Fig. 8a, e.g. S_0=0,4). As for the static equilibrium position angle, its value is very small for 12-pad bearing and is larger for 16-pad one (Fig. 8b).

Friction force that was determined for tilting 16-pad bearings dose not vary much in case of variation of pad relative clearance for two considered values of bearing length to diameter values. (Fig. 9).



a) b)

Figure 8. Journal displacement (a) and static equilibrium position angles (b) versus Sommerfeld number



a) b)

Figure 9. Effect of load orientation on the friction force tilting 16-pad journal bearings; a – load on pad, b –load between pads versus Sommerfeld number

Final remarks

The numerical algorithm applied in the calculations of friction force gives reasonable results that can be applied in the design and analysis of journal bearings. Computation and analysis of friction force are very important for bearing performances understanding. The consideration comprised in this paper and the results obtained allow drawing the final remarks that are given below.

1. Multilobe journal bearings show the increase in the friction force at the increase with the number of lobes.
2. The values of friction force show the decrease at the increase in the oil groove extent.

3. Application of the bearings with the lobes of different geometry (LDG) gives new perspectives of the control of friction force as well as other static characteristics of multilobe journal bearings.

In case of tilting-pad bearings the additional effects as the mass of pad, deformations of pad and its support as well as the friction in the pad support should be considered too.

In many cases the importance of the lobe of different geometry in multilobe journal bearings is underestimated; there is not enough understanding on the knowledge how the bearing can influence the performances of the rotating machinery.

Analysis of the obtained results in the form of static characteristics of multilobe bearings with the lobes of different geometry allows the designers to choose them according with the requirements of a specific bearing system, e.g., decrease in the friction force of rotating machines.

Application of the multilobe journal bearings with the lobes of different geometry assures a wide family of such bearings. It gives the great number of bearing types that can be optimised from the point, e.g. the decrease in friction force and obtaining energy savings. New design solutions of multilobe bearings can be applied in, e.g. floating ring bearings design.

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THE FLEXIBILITY EVALUATION IN THE ASSEMBLY WORKSHOP OF A TERMINAL AUTOMOTIVE FACTORY " MIXED-MODEL ASSEMBLY LINES "

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ABSTRACT

The automotive industry, renowned for its dynamism, faces increasing pressure to adapt to ever-evolving market dynamics. In this comprehensive literature review, we delve deep into the industry, with a specific focus on the critical theme of flexibility within mixed-model assembly lines. This theme is encapsulated in our title, "The Flexibility Evaluation in the Assembly Workshop of a Terminal Automotive Factory - Mixed-Model Assembly Lines."

Our exploration commences with a meticulous examination of the theoretical foundations of flexibility, a concept that lies at the very core of automotive manufacturing. We embark on a journey through various facets, ranging from the intricacies of production system configurations to the nuances of assembly line operations, all while critically assessing the very essence of flexibility itself.

This literature review, more than just an academic exercise, serves as the foundational cornerstone for our forthcoming research endeavours. Our ultimate aspiration is to seamlessly integrate the multifaceted insights garnered here into a cohesive framework. This framework will not only contribute to a more profound comprehension of flexibility within the context of the automotive industry but will also pave the way for innovative, real-world solutions to the continually evolving challenges that confront automotive manufacturers.

Our overarching objective transcends the realms of academia; it is intrinsically tied to the betterment of the industry itself. We seek to empower companies navigating the dynamic landscape of the automotive sector by enhancing their competitiveness and operational efficiency. As the industry grapples with unprecedented changes, we believe that the strategic deployment of flexibility can be a transformative force.

In the coming months, we invite you to stay engaged with our ongoing research initiatives. One of our primary areas of focus will be the exploration of the transformative potential of Industry 4.0 on flexibility within the automotive sector. This topic, while briefly introduced here, will be the centrepiece of our subsequent research efforts, wherein we plan to dive deeper into the practical implications of this technological revolution. We look forward to sharing our findings and insights as we continue to bridge the gap between theory and the ever-evolving realities of the automotive industry.

Keywords: Automotive manufacturers, Mixed-model assembly lines ,Flexibility , Theoretical foundations.

Introduction

The automotive industry stands as one of the most dynamic and rapidly evolving sectors in our contemporary world. To maintain competitiveness in a market characterized by demand fluctuations and a growing diversity of vehicle models, automotive manufacturers are increasingly turning to flexible production systems and adaptive assembly line configurations. This literature review delves into various aspects of these challenges and solutions, with a focus on the significance of manufacturing system configurations, assembly line characteristics, and flexibility within the context of the automotive industry.

We will commence our exploration by examining the research of (Koren et al., 1998) and his colleagues, which has underscored the importance of different production system configurations, such as serial, parallel, or hybrid

setups. These configurations have a substantial impact on system performance concerning reliability, productivity, product quality, capacity, scalability, and costs. In an increasingly volatile market environment, traditional serial configurations are revealing limitations in effectively managing product variety and ensuring reliability.

Subsequently, we will delve into the work of researchers like (Giard & Jeunet, 2006; Lafou et al., 2015; Lesert, 2006), who have contributed to our understanding of assembly line characteristics, particularly within the automotive sector. Their research sheds light on the challenges posed by mass customization of vehicles, sequencing complexities on production lines, and the delicate balance required in workload distribution and component consumption.

Lastly, we will explore the concept of flexibility, a pivotal element in enabling automotive companies to adapt to the ever-changing market dynamics. We will examine flexibility from various angles, ranging from general definitions found in scientific literature to in-depth analyses of its specific applications in mixed automotive assembly lines.

This literature review will lay the groundwork for our future research, aiming to integrate these concepts to discover innovative solutions to the evolving challenges faced by the automotive industry. Our objective is to contribute to the enhancement of competitiveness and efficiency for companies operating within this dynamic sector.

Méthodologıe

1. *Literature Review:*

We conducted an in-depth literature review using various academic databases such as Google Scholar, Scopus, and other specialized sources in the field of the automotive industry. Carefully selected keywords, including "flexibility in the automotive industry," "production management," "mixed vehicle models," and "assembly lines," guided our search towards relevant works.

2. *Selection Criteria:*

Articles were chosen based on thematic relevance, work quality, and a balanced representation of different eras. The diversity of methodological approaches was also considered to ensure a comprehensive view of the subject.

3. *Chronological Classification:*

Articles were chronologically classified by decade, facilitating a systematic analysis of the evolution of flexibility approaches over time. This classification allowed for the identification of emerging trends and significant changes in the understanding of flexibility in the automotive industry.

4. *Internship at Renault:*

As part of this study, we plan to enhance our practical understanding by undertaking an internship at Renault, a company renowned for its expertise in managing flexibility in workstations on assembly lines. This internship will enable us to transition from theory to operational reality and closely observe real challenges and solutions in the context of the automotive industry.

5. *Data Management:*

Data collected during our literature review and futur internship will be qualitatively processed. We will employ an analytical approach to extract relevant information regarding trends, challenges, and solutions related to flexibility in the automotive industry.

Literature Review on Manufacturing System Configurations

Production System Configurations and Their Impact

Yoram Koren et al.'s study underscores the importance of different production system configurations, including serial, parallel, or hybrid configurations. These configurations significantly influence system

performance in terms of reliability, productivity, product quality, capacity, scalability, and cost (Koren et al., 1998).

In traditional systems designed for medium to high-volume production, serial configurations are common. However, this approach has limitations in a global competitiveness context characterized by significant demand fluctuations and increasing product diversity. Serial production lines are not efficient in managing product variety and exhibit relatively low reliability, as the failure of one machine can halt the entire system.

Koren and his colleagues' article , highlights the importance of selecting the right production system configuration to optimize performance. They emphasize that when choosing a manufacturing system, it is crucial to consider measures such as initial system cost, quality, reliability, scalability capacity, the number of product types the system can produce, and conversion time between products. These factors are essential for assessing the overall performance of a production system.

Literature Review on Assembly Line Characteristics

Before delving into our methodology for assessing workplace flexibility, it is essential to establish a fundamental understanding of assembly line characteristics. The insights provided by (Lesert, 2006; Lesert et al., 2010) and (Giard & Jeunet, 2006) offer valuable perspectives on the intricacies of assembly lines, particularly in the automotive industry.

Giard's Perspective (2006)

Giard emphasizes the increasing complexity of the automotive industry due to mass customization of vehicles . He highlights the challenges posed by assembling alternative modules and customer-requested options, leading to sequencing difficulties on the production line. Giard also underscores the dual objectives of workload balancing and component consumption, acknowledging the delicate nature of reconciling these goals (Giard & Jeunet, 2006).

Insights from Lesert (2006, 2010)

Lesert complements this view by shedding light on cost and industrial constraints related to workstation operators. He identifies "workload peaks" for certain vehicles, impacting planning, and underscores the importance of flexibility in absorbing forecast errors, sequencing difficulties, and production uncertainties (Lesert, 2006; Lesert et al., 2010).

This preliminary understanding of challenges and solutions drawn from the works of Lesert and Giard forms the basis of our assessment of workplace flexibility in the specific context of automotive assembly lines.

Analysis of Mixed Assembly Lines

Mr. Lafou and al. were providing a complementary perspective by focusing on production system configurations for mixed automotive assembly lines It underscores the need for high flexibility to effectively manage a variety of vehicle models, respond to changing market demands, and maintain profitable production. (Lafou et al., 2015).

Methodological Approaches

Mr. Lafou et al.'s article provides a complementary perspective by focusing on production system configurations for mixed automotive assembly lines. It underscores the need for high flexibility to effectively manage a variety of vehicle models, respond to changing market demands, and maintain profitable production (Lafou et al., 2015).

Moreover, in the context of our future internship at Renault, a company known for its emphasis on mixed model assembly, our focus will be directed towards gaining practical insights into the implementation of flexibility strategies discussed in the literature. This practical experience will further inform our understanding of the challenges and solutions associated with flexibility in the automotive industry.

Literature Review on Flexibility in the Automotive Industry

Understanding assembly lines and manufacturing system configurations in the automotive industry leads us to examine a fundamental aspect transcending these structural elements: flexibility. This concept is crucial in the dynamic context of the automotive industry, where it plays a central role in adapting to constant changes, such as the increasing diversification of vehicle models and market demand fluctuations.

We will approach flexibility from two angles: a general perspective derived from scientific literature and a deeper analysis of its specificity in mixed automotive assembly lines.

General Definition of Flexibility

The concept of flexibility, especially in the context of Flexible Manufacturing Systems (FMS) (Maulida, 2023) is defined as the ability of a system or process to adjust to changes with minimal or no impact on its final production. This definition is attributed to various authors, including (Rosenhead & Elton, 1972.), (Slack, 1987), (Sethi & Sethi, 1990)

The types of flexibility within FMS are categorized into three levels: (Maulida, 2023)

Necessary Flexibility (Operational Focus), Sufficient Flexibility (Tactical Focus), and Competitive Flexibility (Strategic Focus). Each of these levels encompasses specific types of flexibility, as follows:

1. Necessary Flexibility (Operational Focus):

Machine: The system's ability to change operations without significant effort.

Material Handling: The ability to efficiently move different types of parts for proper positioning and processing.

Operation: The ability to produce the part in different ways with alternative process plans.

Automation: The automation's capacity to perform different operations and/or add operations.

Labor: The ability to modify the number of workers, tasks performed by workers, and responsibilities.

Process: Relating to all types of parts that the system can produce without major configuration.

Routing: The ability to produce a part through alternative routes.

The elements of necessary flexibility are illustrated by (Figure.2) as follows:

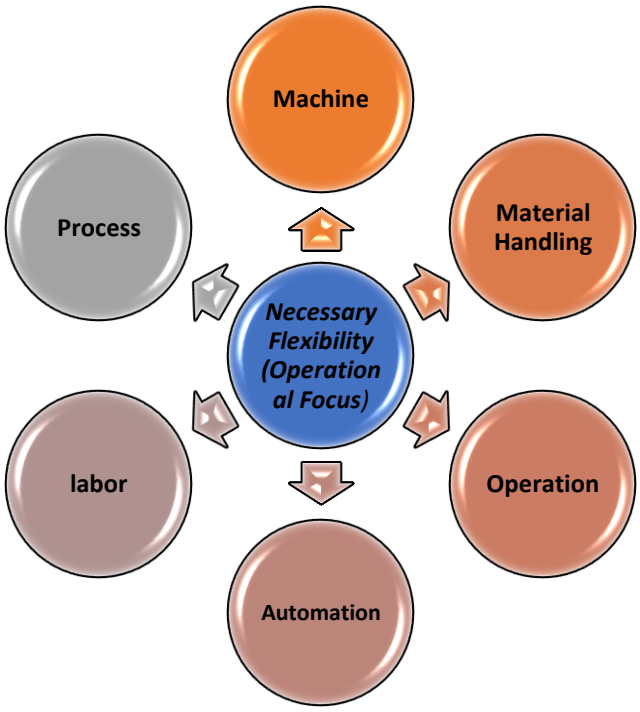

Figure 1. The necessary flexibility clasifications for

2. Sufficient Flexibility (Tactical Focus) :

Product: Ease with which new parts can be added or substituted for existing ones.

New Design: Ease with which the system produces a product with different shapes and/or dimensions.

Delivery: Ease of transporting materials to the manufacturing facility and within facility operations.

Volume: Capacity to operate profitably at different levels of overall product production.

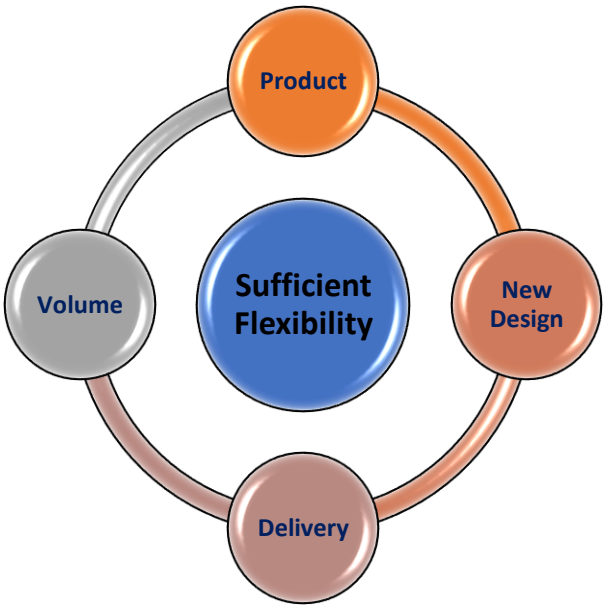

Figure 2. Sufficient Flexibility (Tactical Focus)

3. Competitive Flexibility (Strategic Focus) :

Expansion: Ease with which capacity and capability can be increased when needed.

Program: The system's ability to operate virtually unsupervised for a sufficiently long period.

Production: The universe of part types that the FMS can produce.

Market: Ease with which the manufacturing system can adapt to a changing market environment.

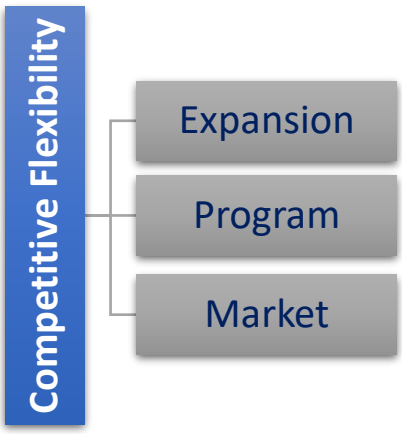

Figure 3. The competitive Flexibiclity casifications

Application in the Automotive Industry

The definition of flexibility in the context of an automotive, according to (Lesert and al., 2010), is oriented towards the production means' ability to respond to production uncertainties, forecast errors, and vehicle

sequencing difficulties while minimizing production costs. This definition emphasizes both volume flexibility and mix-product flexibility. The former refers to the production system's capacity to vary its production volume to meet customer demand.

In conclusion, flexibility in the automotive industry is a multidimensional concept that requires a deep understanding of sector-specific needs. Academic research provides a strong framework for understanding and evaluating flexibility, enabling companies to proactively adapt to market changes and maintain competitiveness

Conclusıons and perspectıves

In conclusion, by integrating Koren et al.'s ideas into the context of the automotive industry, we emphasize the need for a systemic approach in the design of assembly lines. Their work provides analytical tools to assist system designers in selecting the appropriate production system configuration, which is particularly relevant to an automotive industry facing unique challenges of flexibility and product variability. This perspective complements the approaches of Lesert and Mr. Lafou et al., providing a solid foundation for understanding and evaluating flexibility in various automotive production contexts.

Our analysis of the theoretical foundations of flexibility in the automotive industry has equipped us with a deep understanding of the fundamental concepts essential for building flexible production systems. However, our journey doesn't end here. In our forthcoming work, we will delve into technological advancements and the impact of Industry 4.0 on flexibility.

The transition to Industry 4.0 presents exciting opportunities for enhancing production process flexibility. By combining the theoretical foundations we've discussed with the technological advancements of Industry 4.0, we aim to discover innovative ways to strengthen flexibility in the automotive industry. This next phase of our research will enable us to practically explore how to integrate these two approaches, the theoretical foundations and technological evolution, to meet changing market demands and maintain competitiveness. Our upcoming internship, scheduled to commence in early 2024, will provide a platform for putting these concepts into practice and exploring the synergy between theory and industrial reality. We eagerly anticipate sharing our findings on this matter in our future communications.

Information Note

I would like to emphasize my strong interest in the research topic and my eagerness to collaborate further in this exciting field. I am open to potential partnerships, whether with individuals, fellow researchers, or organizations who share a similar interest in these themes. Please do not hesitate to reach out to me via email at the following address: lahyani.houda@etu.uae.ac.ma.

I am enthusiastic about engaging in discussions and exploring additional perspectives with like-minded individuals who are passionate about flexibility in the automotive industry, particularly in the context of implementing Industry 4.0 principles.

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EFFECT OF AIRFOIL THICKNESS ON FLOW OVER THE SYMMETRIC AIRFOILS: PART II- NUMERICAL ANALYSIS

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ABSTRACT

This study investigated numerically and experimentally NACA 0012, NACA 0015, and NACA 0018 airfoils at AoA=8° and Reynolds number of 1.5x105. Oil-flow visualization experiments were used to compare laminar separation bubble, separation, and reattachment results on the airfoil's upper surface with skin friction coefficient contours obtained from numerical analyses. The k-w SST transition model was run in the numerical analyses, where two different boundary conditions were tested: symmetry and wall conditions. Comparisons indicated that the transition model provided accurate results and the wall condition was in good agreement with the experimental data. The examination of aerodynamic force coefficients for symmetrical airfoils revealed that the CL value for NACA0012 was 0.6, which increased to 0.64 for the thicker NACA0015 airfoil. However, the lift force coefficient of the NACA0018 airfoil decreased to 0.52 with a further increase in thickness. Furthermore, it was observed that the drag force coefficients increased as the thickness increased.

Keywords: Aerodynamic, CFD, Airfoil

Introduction

Interest in renewable energy sources has grown recently in response to escalating ecological issues. One of these renewable energy sources, wind energy, is converted to electricity by wind turbines, which are evolving along with technology. Examining the research in this area, studied how to improve the efficiency of a vertical-axis wind turbine using the Taguchi method (Chen et al. 2021). Compared a horizontal-axis wind turbine with a vertical-axis wind turbine using energy and exergy analysis with numerical analysis (Pope et al. 2010).

The blades, which are one of the most important elements of wind turbines, have a great role in terms of energy efficiency. examined wind turbine blades at different tip speed ratios. Then, they compared turbine models and mentioned the structural performance of thick airfoils and the aerodynamic performance of thin airfoils (Schubel et al. 2012). Considered the blade to be partially flexible on the suction surface and conducted many different experimental studies on this subject (Genç et al. 2020). Besides, the blade's aerodynamic performance was improved using partial flexibility. Wind turbine blade models are still being developed today. Conducted extensive experiments on the NACA 2415 airfoil, such as force and pressure measurements at low Reynolds

at different angles of attack, flow visualization with the smoke wire technique, and velocity measurement with the hot wire system (Açıkel et al. 2016). The laminar separation bubble and stall formations depended on the angle of attack and Reynolds number. The results showed that low Reynolds number aerodynamics require new investigations.

Used the oil flow visualization technique and infrared thermography at a $4.7x10^4$ Reynolds number between angles of attack of 0° and 13°. The study identified separation and reattachment regions in the flow (Ghorbani et al. 2018). Studied experimentally and numerically the flow over the NACA 2415 airfoil at low Reynolds number flows. They visualized the flow using the oil visualization experiment. For force measurement, a computer-controlled automatic angle changing force measurement system was used. In the numerical simulations, they observed that the results matched the experimental results (Genç et al. 2012). İnvestigated the pitching moment in a digital environment by meshing the area around the wing with the help of MATLAB at different Reynolds numbers ($10^4 < Re < 10^5$) and angles of attack for the NACA 0012 airfoil(Devi et al. 2022). NACA0012 conducted a number of numerical and experimental studies to measure the tip vortices of the airfoil. They used the LES turbulence model in the numerical analysis, and experimentally performed a flow visualization experiment with oil. Then, the numerical pressure distributions were compared with the experimental distributions(Imamura et al. 2005). Analyzed the flow on the airfoil at different angles of attack using different turbulence models. The numerical results pointed out that the transition model produced substantial results (Özden et al. 2022). Studied the flow on the NACA0018 airfoil at a low Reynolds number ($1.6x10^5$) and different angles of attack (0°-11°). They used the transition SST and the k-ω SST turbulence models under the same conditions. As a result, the transition SST model was found to be more appropriate(Rogowski et al. 2021).

Carried out numerical and experimental studies on the NACA4412 airfoil. In the study, they performed analyses with two different turbulence models (transition SST and $k-k_L-w$ transition models). The analysis results were compared with the oil flow visualization and force measurement results. While both models obtained successful flow prediction results on the airfoil surface, and the $k-k_L-w$ transition model results in force coefficient comparisons gave results closer to the experiments(Karasu et al. 2018).

In similar studies (Özden et al. 2022) ,smoke, oil, hot wire anemometer, and force coefficient measurements were carried out on the airfoil profiles. The common goal of these studies was to understand the unsteady aerodynamics at low Reynolds numbers on airfoils. Studies show that the change in airfoil thickness directly affects wing aerodynamic performance. Studied flow control over a diamond-shaped cylinder using slits using Particle Image Velocimetry (PIV). To investigate the effect of the slit width/diameter ratio (θ) on the flow over the diamond-shaped cylinder, different θs were studied (Karasu 2020). The researchers modeled the flow domain around the airfoil under both symmetrical and wall conditions (Lei et al. 2013). They analyzed and provided an explanation for the formation of vortices behind the airfoil under these two different conditions. The results showed that the vortices formed more smoothly under the symmetrical condition, whereas under the wall condition, the vortices formed in a more confused manner.

In this study, numerical analyses of the symmetrical airfoils (NACA 0012, NACA 0015, and NACA 0018) at the angle of attack of 8° at a low Reynolds number ($1.5x10^5$) were performed. In numerical modeling, enclosure was defined as wall and symmetry, respectively, under the same conditions. The oil flow visualization experiment was performed to determine the LSB regions. The force measurement was conducted to obtain the force coefficients. As a result, the numerical and experimental results were compared.

Materials and Methods

Numerical Method

Airfoil models for the numerical modeling were designed using ANSYS SpaceClaim software. The dimensions of the computational domain (the height is 20x chord length and the length is 30x chord length) were determined based on the previous studies (Özden et al. 2022, Karasu et al. 2018). The numerical flow analyses were conducted in the ANSYS Fluent software. Figure 1 shows the domain, boundary conditions, and dimensions. A suitable mesh was chosen to ensure that the numerical analysis was both precise and accurate. The tetra mesh structure was applied to the flow domain, and boundary layer mesh was formed on the airfoil. Furthermore, an inflation mesh was used to provide a detailed examination of the flow over the airfoil.

Boundary conditions has a significant role in numerical analyses. In addition to well-known boundary conditions such as inlet and outlet, researchers also employ symmetry or walls boundary conditions. The wall is a boundary condition that satisfies the no-slip condition, while the friction coefficient is very low. The symmetry is a boundary condition that disregards friction, assuming the item is in an atmosphere.

As shown in Figure 1a, all surfaces in the study aside from the inlet, outlet, and airfoil were first classified as walls and subjected to analysis. It is not anticipated that the airfoil would be significantly impacted by the wall boundary conditions. Moreover, the symmetry boundary conditions, which were applied to surfaces other than the inlet, outlet, and airfoil, are the focus of this study. The studies were also carried out once again for both boundary conditions while accounting for different flow phenomena, and the results were then contrasted with those from the experiments.

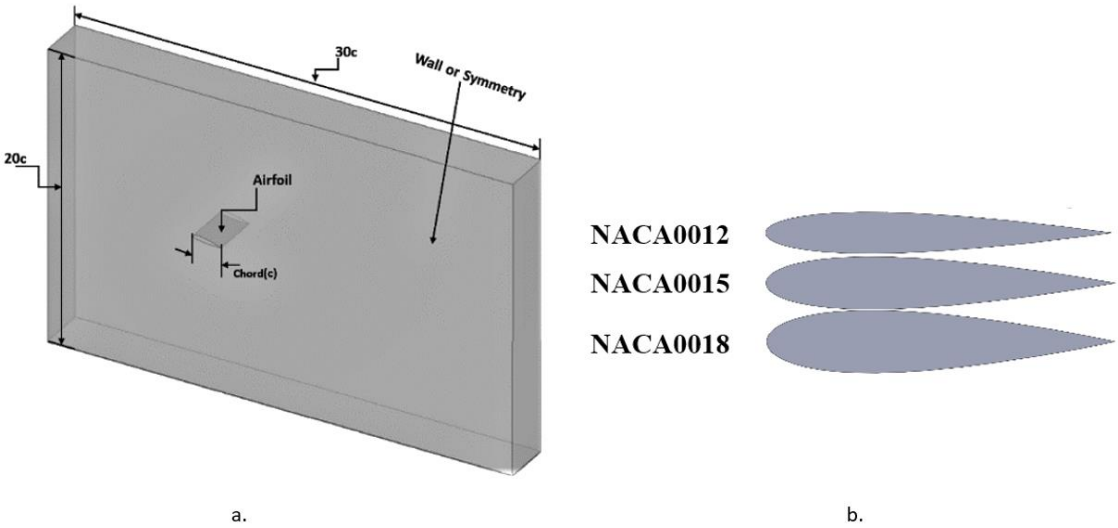


Figure 1 a.) Flow domain, b) airfoils

Table 1. Mesh Independence study results

Mesh size	C_L	C_D
$0.06x10^7$	0.60	0.03
$0.1x10^7$	0.60	0.03
$0.7x10^7$	0.58	0.03
$1.4x10^7$	0.58	0.03
$2.0x10^7$	0.58	0.03

A mesh independence study was conducted using different node counts. In this study, aerodynamic force coefficients were obtained by performing analyses with increasing mesh numbers at predetermined intervals. The results indicated that the findings did not show significant changes beyond the $1.4x10^7$ mesh number. As a result, the analyses were continued using this mesh number.

The determination of the boundary layer mesh was considered a crucial step in solving the flow over the model. As shown in Figure 2, a boundary layer mesh with 20-layer was created around the airfoil based on the y+ calculation that depended on the Reynolds number.

The transition SST model was utilized in Ansys Fluent software, which generally required y+ values between 1 and 5 to ensure accurate results. Therefore, the y+ value was close to 1 for achieving a more reliable outcome.

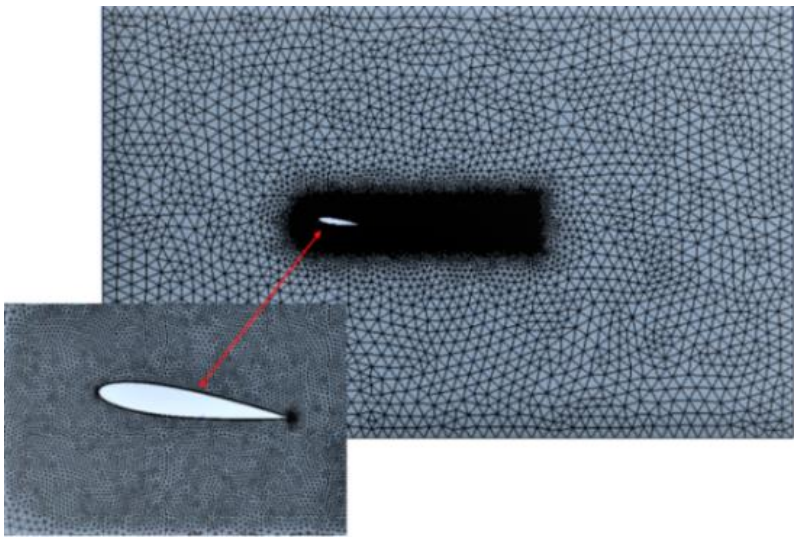


Figure 2. The detailed view of the mesh structure of the airfoil.

At a certain angle of attack (8°), the numerical calculations for NACA 0012, NACA 0015, NACA 0018 airfoils was done at a Reynolds number (Re=1.5x10^5) in Ansys Fluent software.

Wall shear contours were obtained from the results of the simulation, and C_{fx} graphics were prepared with dividing by dynamic pressure according to Equation 1 to analyze the flow separations.

$$Cf_x = \frac{Wall\ Shear\ X}{0.5*\rho*u^2} \quad (1)$$

Materials and Methods

The experiments in the other conference paper (Part-I) were carried out in a wind tunnel with a cross-sectional area of 0.5 m x 0.5 m, belonging to the Erciyes University-Wind Engineering and Aerodynamics Research Group (WEAR) in Figure 3. The wind tunnel has a speed range of 5 m/s to 45 m/s. The tunnel's turbulence level is 0.3% to 0.9% (Ragowski et al. 2021).

Figure 3. Wind tunnel test setup

Airfoils and Experimental Method

The airfoil models were designed with academic-based ANSYS SpaceClaim software. The designed airfoils were produced using a 3D printer (Fig 4). To prevent tip vortex effects, endplates were mounted to both ends of the airfoils. In order to ensure the same conditions for the airfoils used in the experimental studies, the airfoils

were numerically analyzed. The chord length of the airfoil models (NACA0012, NACA0015, and NACA0018) was 0.18 m and the span length was 0.3 m.

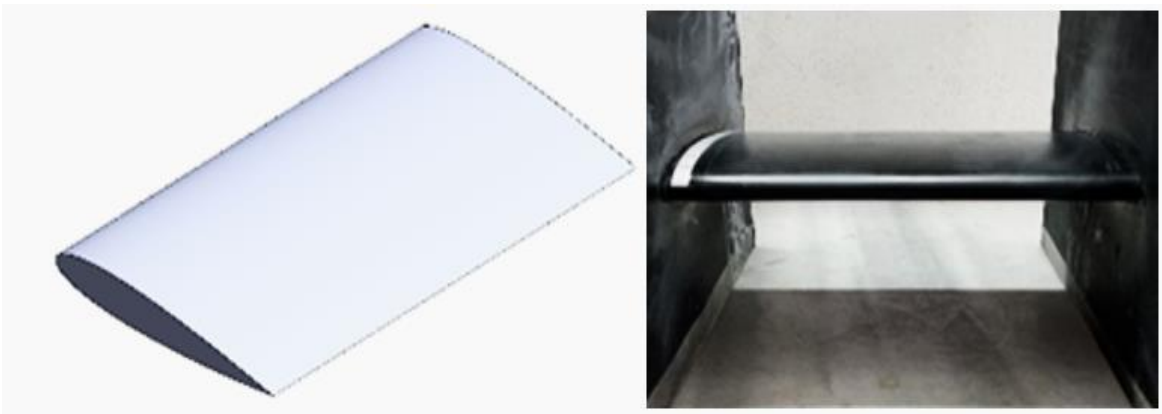


Figure 4. 3D model and a produced model (NACA0015)

Oil-flow Visualization

The oil flow visualization technique is one of the flow imaging techniques used to examine flow motion on a body by adding oil or paint to the flow. Oil flow visualization is a simple and effective way to visualize flow phenomena on the airfoil surface. The ratio and type of material in the mixture are essential when performing the oil method. The mixture must be in the correct ratio to show the flow movements in the boundary layer because the inertial forces of the moving oil must be viscous and lower than the surface tension (Awasthi et al. 2018). To prepare the mixture correctly, a mixture of motor oil, kerosene, titanium dioxide, and oleic acid was used to conduct the oil visualization test. It was essential to ensure that the model was clean and free of any residues that could block the oil flow. Once the mixture was prepared, the test environment was adequately illuminated. The next step involved spreading the mixture onto the airfoil model, followed by adjusting and operating the wind tunnel according to the appropriate Reynolds number. The Reynolds number is a dimensionless parameter that characterizes fluid flow and is an essential factor in determining flow patterns. Finally, photos or videos were taken to record the situation created by the latest flow on the airfoil profile. This data was used to analyze the flow characteristics and evaluate the effectiveness of the airfoil design.

Force Measurements

During the oil flow visualization experiment, a computer-based automatic angle shift force measurement system was used to measure the lift and drag forces acting on the airfoil. Strain gauges were used to make force measurements during the experiment. The force values obtained were then converted into force coefficients (C_L, C_D) using Equation 2.

$$C_n = \frac{F_n}{(\frac{1}{2}\rho U_\infty^2 S)} \quad (2)$$

Findings and Discussion

Oil flow visualization experiments were compared with numerical studies. As indicated in Figure 5, Figure 6 and Figure 7, the numerical results for the symmetry boundary definition are shown on the left, followed by the oil test result, and the wall boundary definition is shown on the right. On the graphs, red represents the highest value while blue represents the lowest. The separation regions are visible at the regions below 0 in the Cfx graphs. Separation flow zones are those that move from white to dark blue. The flow direction was determined from left to right in Figure 5- Figure 7.

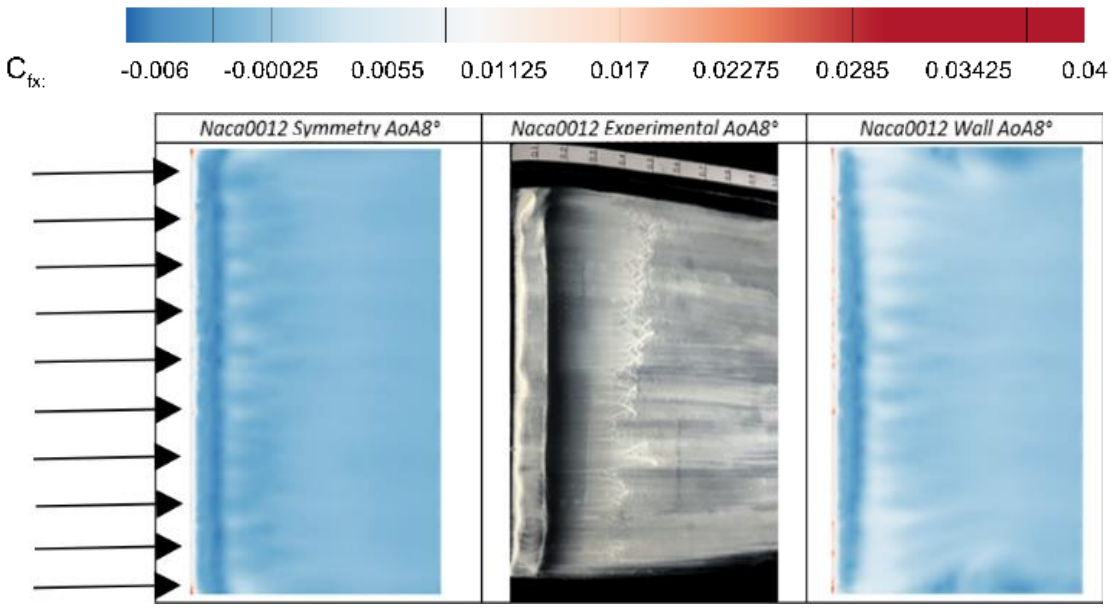


Figure 5. The oil-flow visualization and numerical results (C_{fx}), (Re= $1.5x10^5$ AoA=8°, NACA0012)

As in the Cfx graphs, it is seen that the low-speed region approaches the trailing edge with an increase in thickness. While the solutions were made in 3D, the observation plane was created in the middle of the airfoil. Velocity values at the plane showed that the effects of the walls on the edges were not seen in these figures obtained from the middle of the airfoil. And also, it seemed that there was no difference between the wall and symmetry definitions. The thickness increased from NACA0012 to the NACA0018 airfoil, and the thickness of the NACA0018 airfoil was the largest among the airfoils considered. In the results, it was seen that with the increase in the thickness of the airfoil, the separation point approached from the leading edge to the trailing edge Demir et al. 2017, Genç et al. 2008).

Velocity contours were given in Figure 8. In order to make comparisons, visualization was done as u/U_∞ in the graphics. In the graphs, blue regions showed low-speed values, and the red showed maximum-speed values. As the thickness of the airfoil increased, there was a gradual change in the location of the flow separation points on the airfoil. In numerical analysis, when the boundary conditions for the NACA0012 airfoil were defined as symmetrical, the separation point was located at 0.09 and the reattachment point was at 0.31. When it was defined as a wall condition, the separation point was at 0.035 and the reattachment point was at 0.14. When compared with the experimental results, the separation point was at 0.02 and the reattachment point was at 0.14.

In the case of NACA0015, when the thickness of the airfoil increased, the separation points of the flow on the airfoil changed progressively, as shown in Figure 8. In numerical analysis, when the boundary conditions for the NACA0015 airfoil were defined as symmetry, the separation point was 0.05 and the attachment point was 0.28. If the domain was defined as a wall, the separation point was 0.06 and the attachment point was 0.2. When these values were compared with the experimental results, the separation point was measured as 0.09, and the attachment point was obtained as 0.29 in the experimental study.

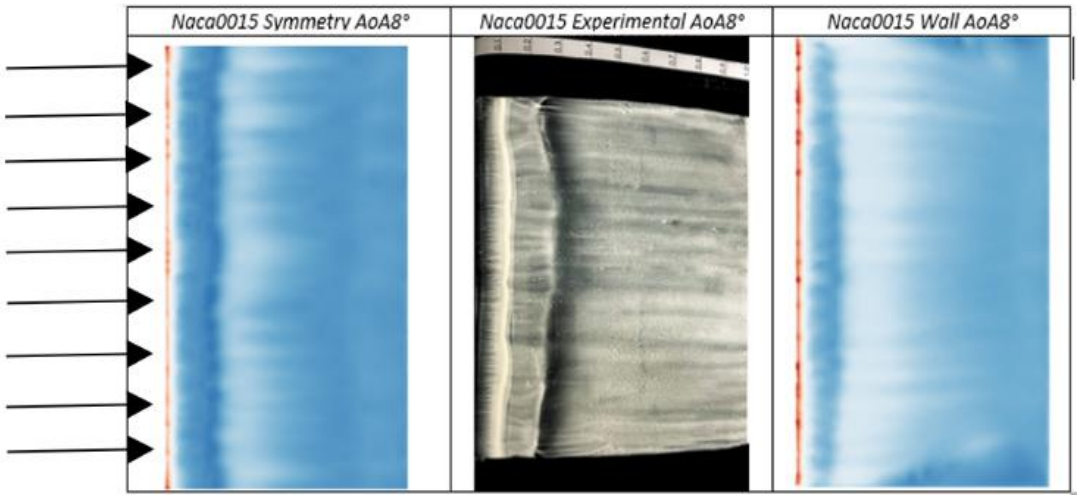


Figure 6. The oil-flow visualization and numerical results (C_{fx}), (Re= $1.5x10^5$ AoA=8°, NACA0015)

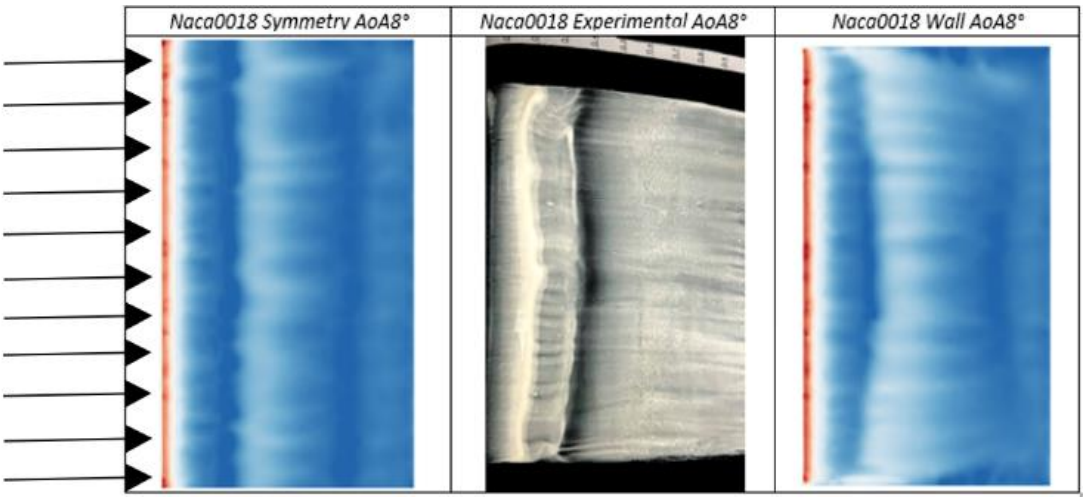
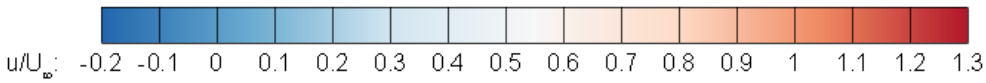


Figure 7. The oil-flow visualization and numerical results (C_{fx}), (Re= $1.5x10^5$ AoA=8°, NACA0018)

In the numerical analysis for NACA0018, when the boundary conditions for the NACA0018 airfoil were defined as symmetry, the separation point was 0.09 and the reattachment point is 0.32. If the domain was defined as a wall, the separation point was 0.1 and the reattachment point was 0.3. When these values are compared with the experimental results, the separation point was found to be 0.11 and the reattachment point was 0.36 in the experimental study.



Symmetry Wall

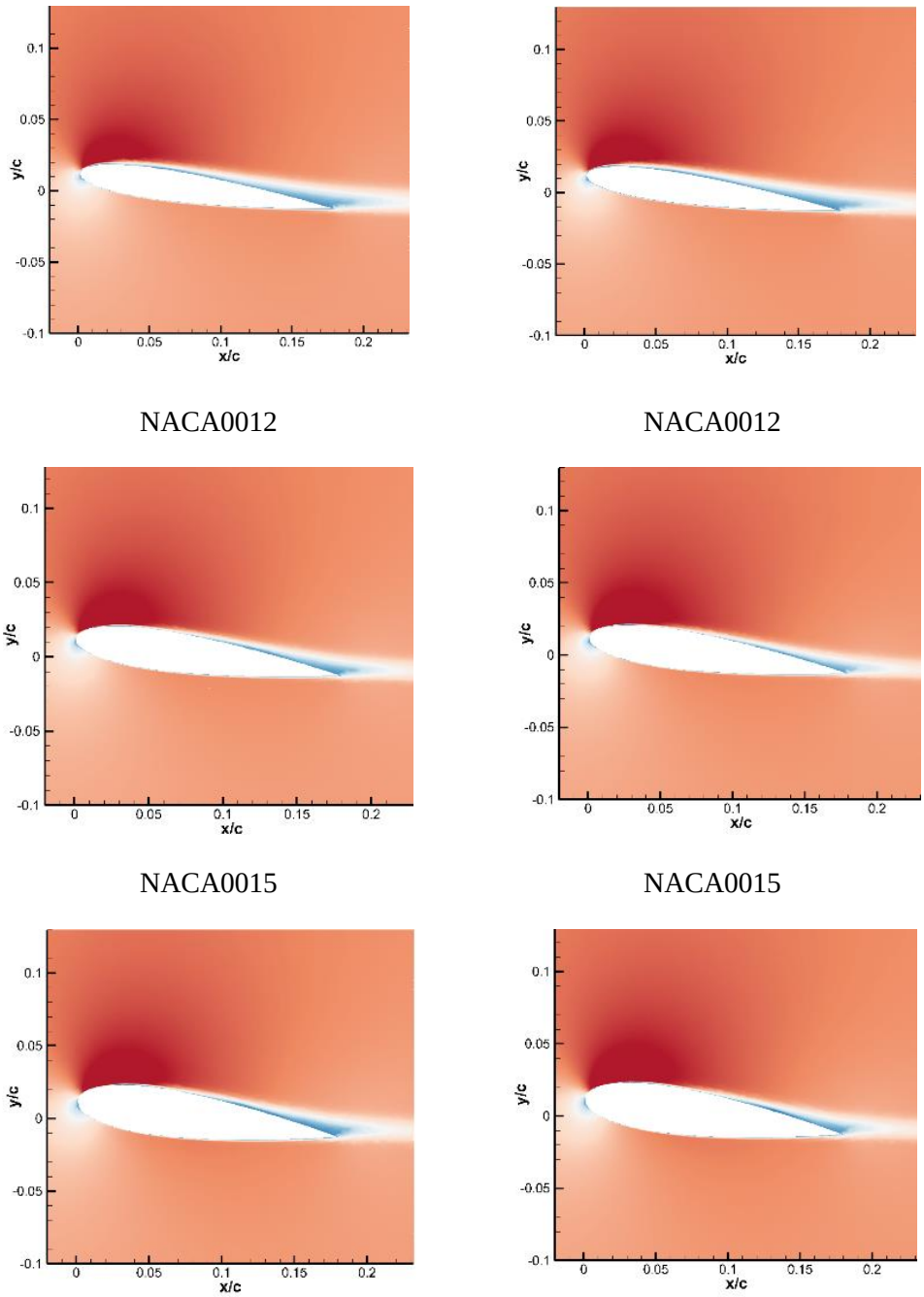


Figure 8. Numerical velocity contours, AoA=8

Numerical and experimental comparisons of the force coefficients were presented in Table 1. While similar results were obtained in the lift force coefficients, there were differences in the drag force coefficients. The reason for these differences was the apparatus used to connect the airfoil to the force system in experimental systems. While the drag force on the airfoil could be determined directly in numerical studies, this was not possible in experimental studies.

Table 2. Aerodynamic Force Coefficients at AoA=8°

	Numerical				Experiment	
	Symmetry		Wall			
	C_L	C_D	C_L	C_D	C_L	C_D
NACA 0012	0.60	0.04	0.61	0.04	0.60	0.10
NACA 0015	0.61	0.031	0.63	0.04	0.64	0.12
NACA 0018	0.58	0.031	0.59	0.04	0.52	0.14

Conclusion and Recommendations

In this study, the NACA0012, NACA0015, and NACA0018 airfoils was used to compare with numerical and experimental studies. Two distinct scenarios were numerically examined while conducting oil-flow testing and force measurement studies. Similar results were obtained when the numerical and experimental data were compared. Particularly, the numerical wall definition led to results that were more consistent with the studies. The end plates employed in tests to prevent tip vortices are the cause of this. Although these structures are transparent and have very low friction, they affect the flow of the wing. This effect also changes the structure of the flow. In this study, these changes were examined clearly in oil tests and C_{fx} contour. Moreover, in the results, it was seen that with the increase in the thickness of the airfoil, the separation point approached from the leading edge to the trailing edge.

Abbreviations and Acronyms

C_f: Skin-Friction Coefficient

C_L: Lift Coefficient

C_D: Drag Coefficient

F: Aerodynamic forces

Re: Reynolds Number

AoA: Angel of Attack

ρ: Air density

u: Local velocity

U_∞: Free Stream Velocity

S: Surface Area

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FORECASTING LAND SHIFT RISKS WITH MAPPING IN MOROCCO'S MIDDLE RIF

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ABSTRACT

To investigate the history of landslides in Morocco, particularly in the Central Rif region between Al Jebha and Al Hoceïma, it's crucial to understand the significant incidents that have occurred. The area has experienced serious events like temporary road closures due to landslides, notably during the Al-Hoceima earthquake of 2003 and extreme rainfall periods. For instance, the Regional Road N° 610 near Kassita and areas near National Route N° 16, close to El Jebha, have been affected.

Given the high risk of ground movement, the Moroccan government's development plans for the Al Hoceima and El Jebha region, including new ports, roads, railway, and urban infrastructure, must consider landslide risks. Selecting locations shielded from landslide risks during the preliminary technical study phase is crucial. This approach is aimed at reducing the maintenance costs of these infrastructures over their operational lifespan.

To support this objective, the creation of landslide risk maps for the study area was undertaken. This involved conducting an inventory of predominant surface soils and rocks and their spatial representation in geotechnical maps, which were previously unavailable. These geotechnical maps were then combined with topographic contour lines to identify areas where soils with weak geotechnical characteristics intersect with steep topographic gradients. The ultimate goal of this work is to delineate areas at high risk of landslides, enhancing safety and infrastructure sustainability in the region.

Keywords: Slope instability, risk map, geotechnical design, Middle Rif Morocco

Introduction

Landslides are globally ranked seventh among major natural hazards [1] after hurricanes and earthquakes. Based on the criterion of damage caused. The Office of U.S. Foreign Disaster Assistance's databases report an average of 700 deaths per year caused by landslides [2] worldwide between 1992 and 2012. Particularly the history of landslides in Morocco [3] is quite eventful and affects various regions of the kingdom, especially in the central Rif region (between Al Jebha and Al Hoceïma). These landslides [4] cause significant material and human damage and hinder the development of the study area. Given the high potential for ground movement [5] in this area and in line with the Moroccan government's desire to promote the development of the Al Hoceïma and El Jebha region through the establishment of new port, road, and railway transport infrastructures. As well as urbanization infrastructure like electrical and potable water networks, it is prudent to select, during the preliminary phase of technical studies, locations that are shielded from the risk of landslides. This approach aims to optimize the costly maintenance of these infrastructures throughout their operational lifespan [6].

With this objective in mind, this article aims to create landslide risk maps in this study area. To do this, we conducted an inventory of the predominant surface soils and rocks [7], with their spatial representation [8] in the form of geotechnical maps using GIS tool [9], which did not exist before this work. Furthermore, we combined these geotechnical maps with topographic contour lines to identify areas where soils with weak geotechnical characteristics intersect with steep topographic gradients.

The examination of geotechnical maps indicates the prevalence of soils with low geotechnical properties[10], specifically Schist, flysch, and marl, whose critical slip angles calculated with numerical simulation using Bishop[11] Method are low (66.67% for Schist as example) in comparison to the substantial natural dip, as illustrated in the dip map. The cartographic precision of this study will be compatible with a scale of 1/50,000. The chosen reference period for the reassessment of cumulative damages is set at fifty (50) years.

Materials and Methods

a- Contextual Overview of the Study Area

As demonstrated by the history of ground movement incidents in the Central Rif (Fig.1), most natural landslides have occurred either during periods of extreme rainfall or in the aftermath of violent earthquakes. Additionally, anthropogenic landslides tend to happen when road construction takes place in geotechnical challenging areas, such as those with flysch [12] or schist [13] formations.

In general, the occurrence of landslides necessitates a combination of extreme rainfall, extreme natural slopes, an active seismic [14] context, and, most importantly, a geotechnical unfavorable substrate.

In the following section, we will provide examples of recent slope movements in the study area:

- Excavation of schist rock cut (Fig.2) along the Taza-Hoceïma expressway [15] (National Road N° 02).
- Large-scale slope movement (Fig.3),At the embankment cut at Kilometric Point 190+500 on National Road N° 16 (Jebha - Amtar).

Figure 2 : ***Excavation of schist rock cut along the Taza-Hoceïma expressway on the National Road N° 02.***

Figure 3 : ***Large-scale slope movement at the embankment cut at Kilometric Point 190+500 on National Road N° 16 (Jebha - Amtar).***

b- Geotechnical data

Based on recent geotechnical surveys carried out by local laboratories in the study region such as LPEE, TRECQ, etc., we have collected a database of geotechnical data [16] necessary for the numerical modeling of the stability of the slopes as shown in the table below:

Table. 1. Geotechcinal Data of soil in Al Hoceïma and El Jebha Region

Soil Nature	Dried Mass volume γ_d (t/m3)	Atterberg liquidity limit W(%)	Cohesion C' (kPa)	Friction angle φ' (°)
Limestone marl of surface	1.658	---	0	38
Greenish sandy marl	1.687	---	41.2	33.6
Indurated				
Marl-Limestone	1.55	7	41.2	26.7
Limestone-Sandstone	1.58	6.8	41.2	23.6
Limestone-schist	1.69	7.3	53.4	34.3
Fractured schist	2.2	---	26 à 32	24 à 27
Sand	1.8		0.1	35
Sandstone	1.52	12.8	Cu =12 à 16	17 à 19
Limestone	1.59	14.3	Cu=8	17
Clay	1.61	11.8	Cu =52	20
Brown silt	1.56 à 1.63	13.7 to 14.3	36.5 à 39.7	20.1 à 23.1
Schist-Gneiss	2	12	40	20

The slope failure angle will be estimated for a 50-meter high slope using the Bishop theory. This choice is justified by the rugged topography of the study area.

c- Topographic Maps

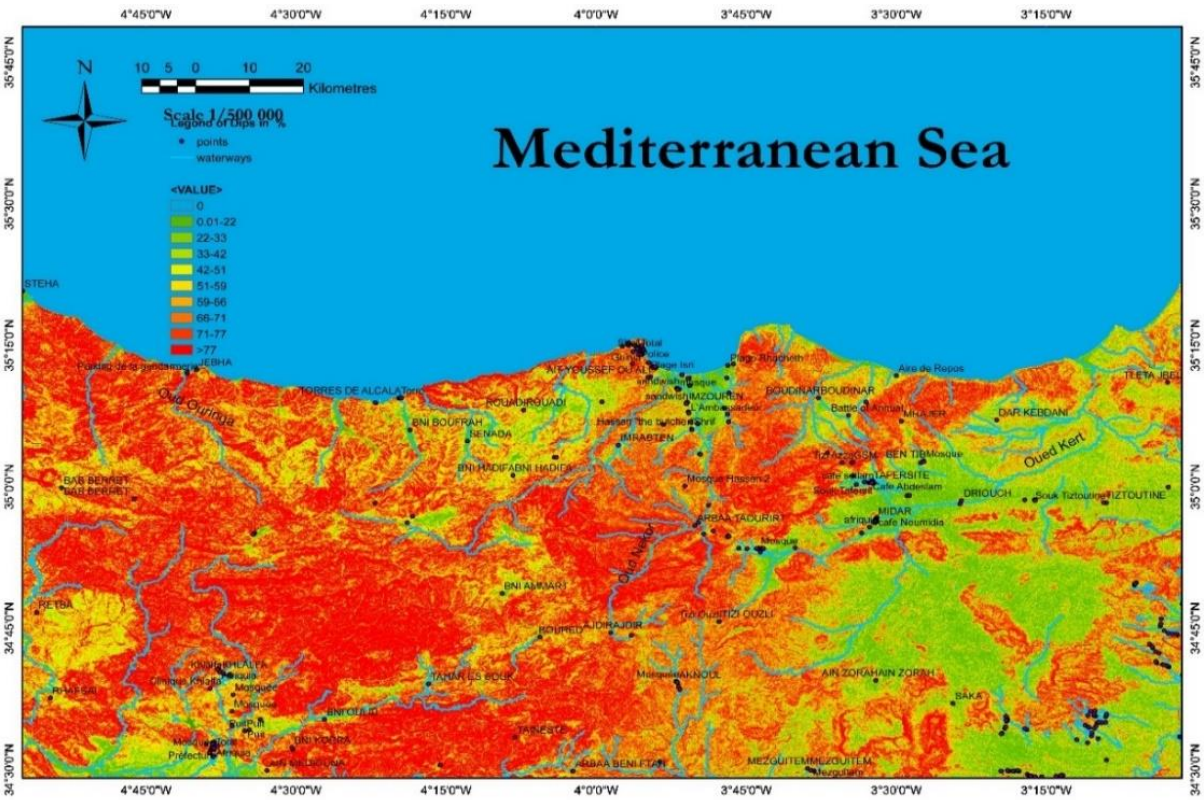

Figure 4 : ***Map of natural land dips of the Study Area***

d- Rainfall data

We collected rainfall (Table 2) data series from Pluviometric stations located near the study area as the "MALHA Station" which is located on the AUDOUR River, overseeing a watershed with an area of 350 square kilometers. It is situated at Moroccan Lambert coordinates (X=532,416, Y=481,744).

Table. 2. Rainfall Date from The Malha Station near to El Jebha Region

Year	Maximum rain Fall (mm)
1999	51,0
2000	86,3
2001	98,2
2002	128,5
2003	64,6
2004	70,5
2005	42,2
2006	61,6
2007	81,2
2008	94,0
2009	85,6
2010	111,8
2011	63,2
2012	80,8
2013	62,0
2014	58,2
2015	25,0
2016	82,0
2017	57,0
2018	42,3
2019	75,6
2020	64,9
2021	31,5

However, it should be noted that the landslides observed in the study area have often occurred because of extreme rainfall events [19]. For example, in the Jebha region, about the month of March 2020, there was a daily record of approximately 136 mm of rainfall (Fig 5). This event was widespread across the entire northern part of the kingdom. Nevertheless, its epicenter coincided with the study area.

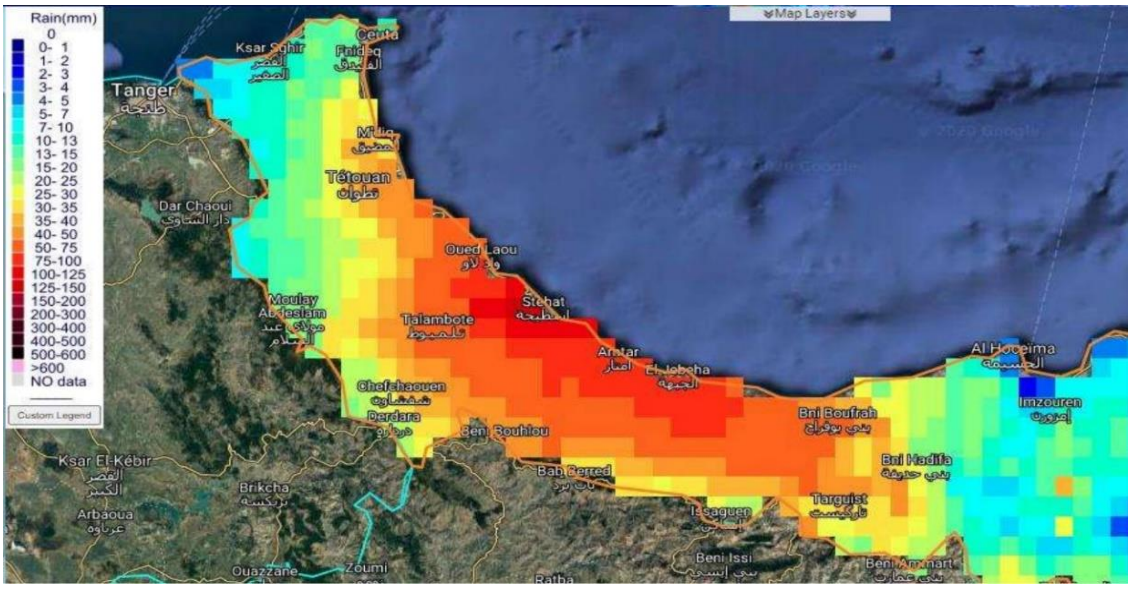

Figure 5 : ***Spatial distribution of daily rainfall in March 2020 around El Jebha Region.***

e- Seismic Maps

From a geotechnical perspective, there is a clear correlation [20] between landslide size and ground motion [21], with larger landslides associated with higher ground motion. Since a landslide occurs when the mobilized shear stress (τ) along the sliding path (circular, planar, parabolic, or any other shape) exceeds the internal shear, resistance τmax of the moving mass, this is facilitated by horizontal seismic acceleration acting on the moving soil mass.

Thus, the primary input value in the calculation algorithm is, therefore, the horizontal seismic acceleration, which was derived from the following seismic map and is approximately 2.2 m/s². This value is within the most severe regulatory zone, M5. As shown in the figure (Fig. 6) below:

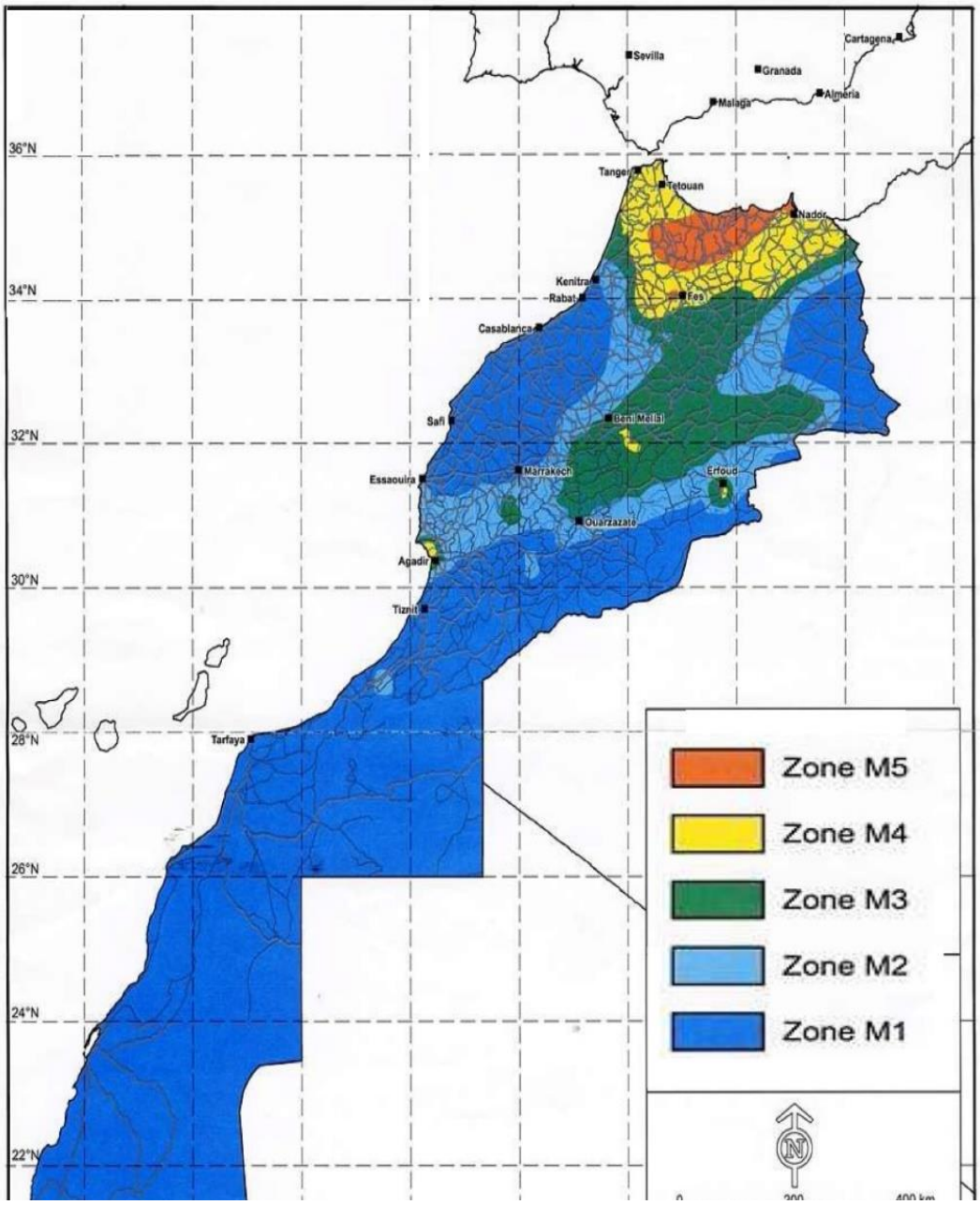

Figure 6: ***Map of regulatory seismic zoning of Morocco.***

Findings and Discussion

a- Result of spatial representation of geotechnical data by GIS tool

By making use of the geological maps previously established by the Ministry of Energy and Mines, in combination with the geotechnical data [22] mentioned previously in this article. GIS technology [23]Enables us to make the superimposition of these two data sets to create geotechnical maps describing the spatial distribution of the predominant soils and rock types in the Al Hoceïma and Al Jebha regions. These geotechnical maps (Fig. 7) , (Fig. 8) , (Fig. 9) and (Fig. 10), are the main product of this research and which are not previously published, will allow us to identify areas at a high risk of landslides [24] by evaluating the critical angle [25] of the encountered soils and rocks.

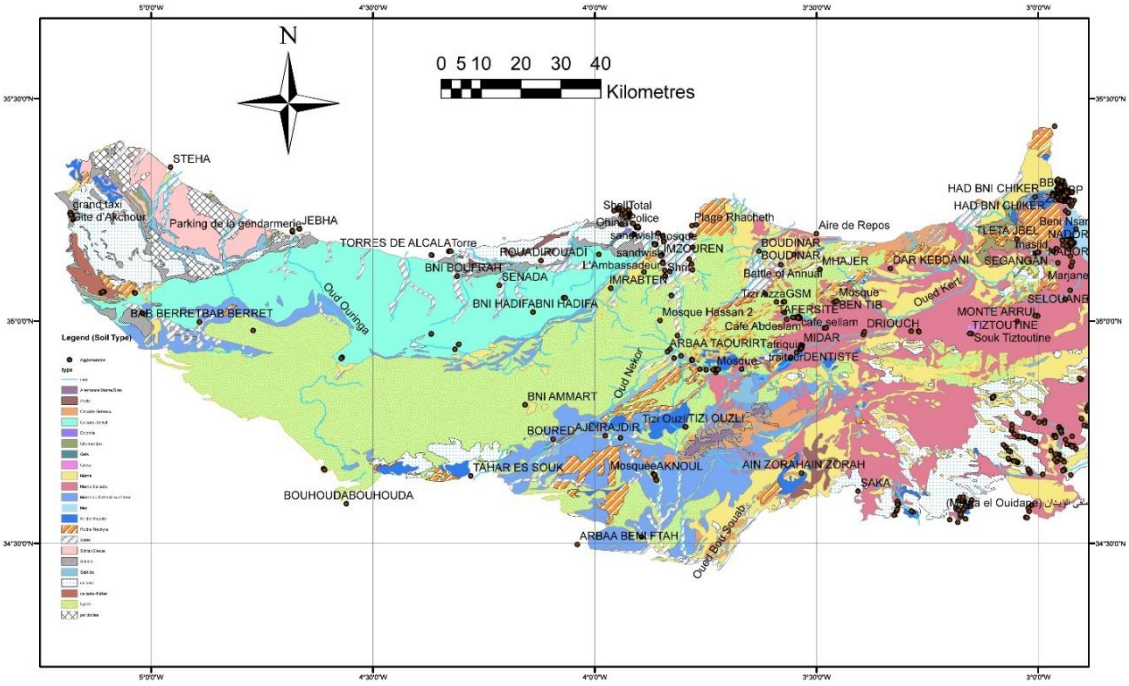

Figure 8 : ***Geotechnical maps (Lithology) of Soils and Rocks in Al Hoceïma and El Jebha Region.***

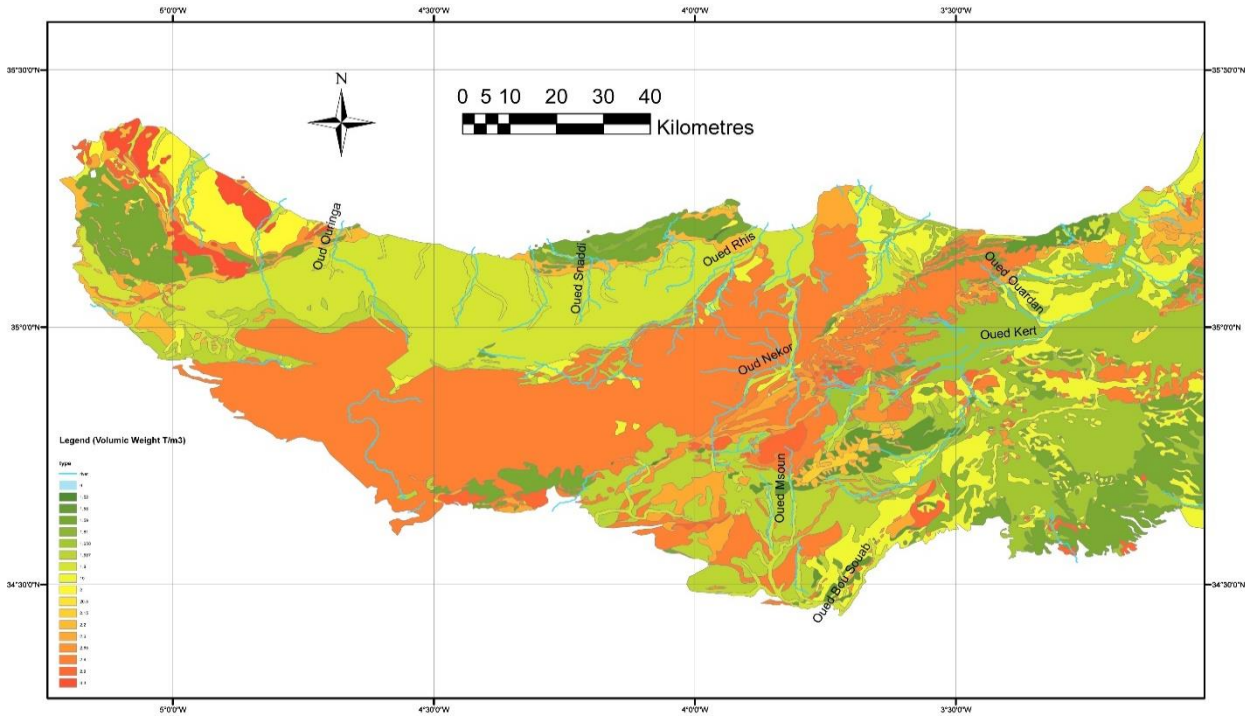

Figure 7 : ***Geotechnical maps (Volumic Weight in T/m3) of Soils and Rocks in Al Hoceïma and El Jebha Region.***

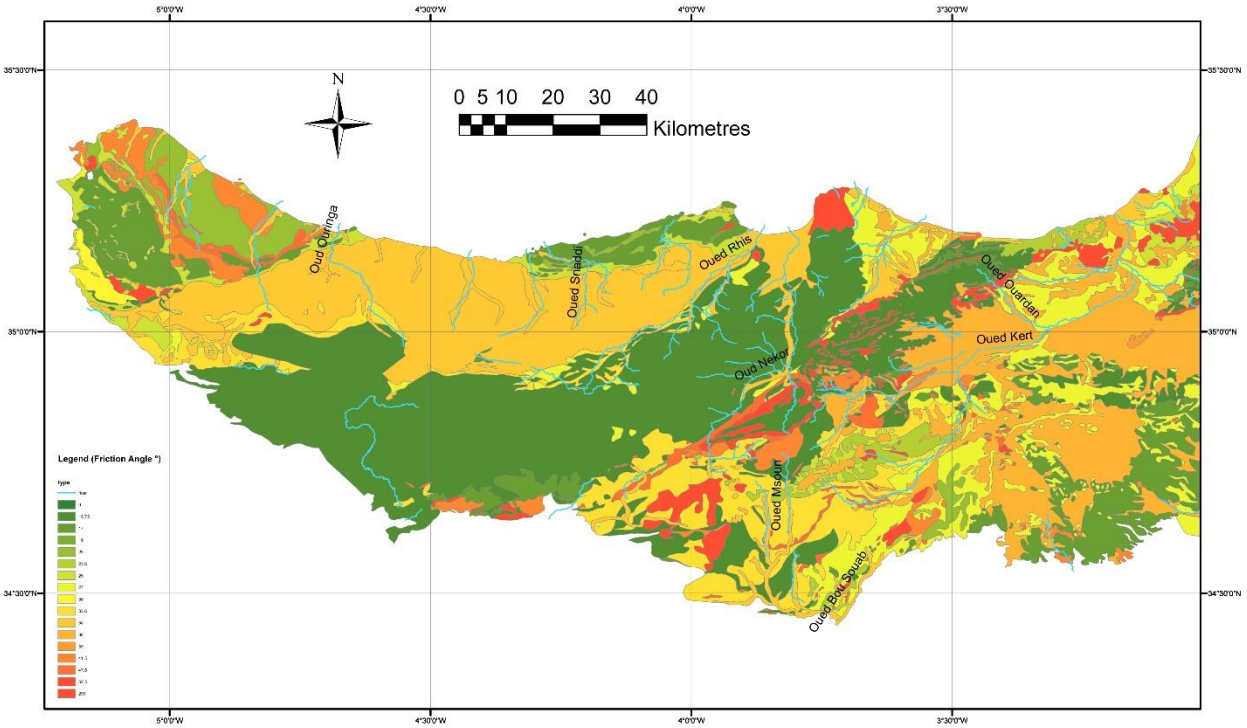

Figure 9: ***Geotechnical maps (Internal Friction Angle in °) of Soils and Rocks in Al Hoceïma and El Jebha Region.***

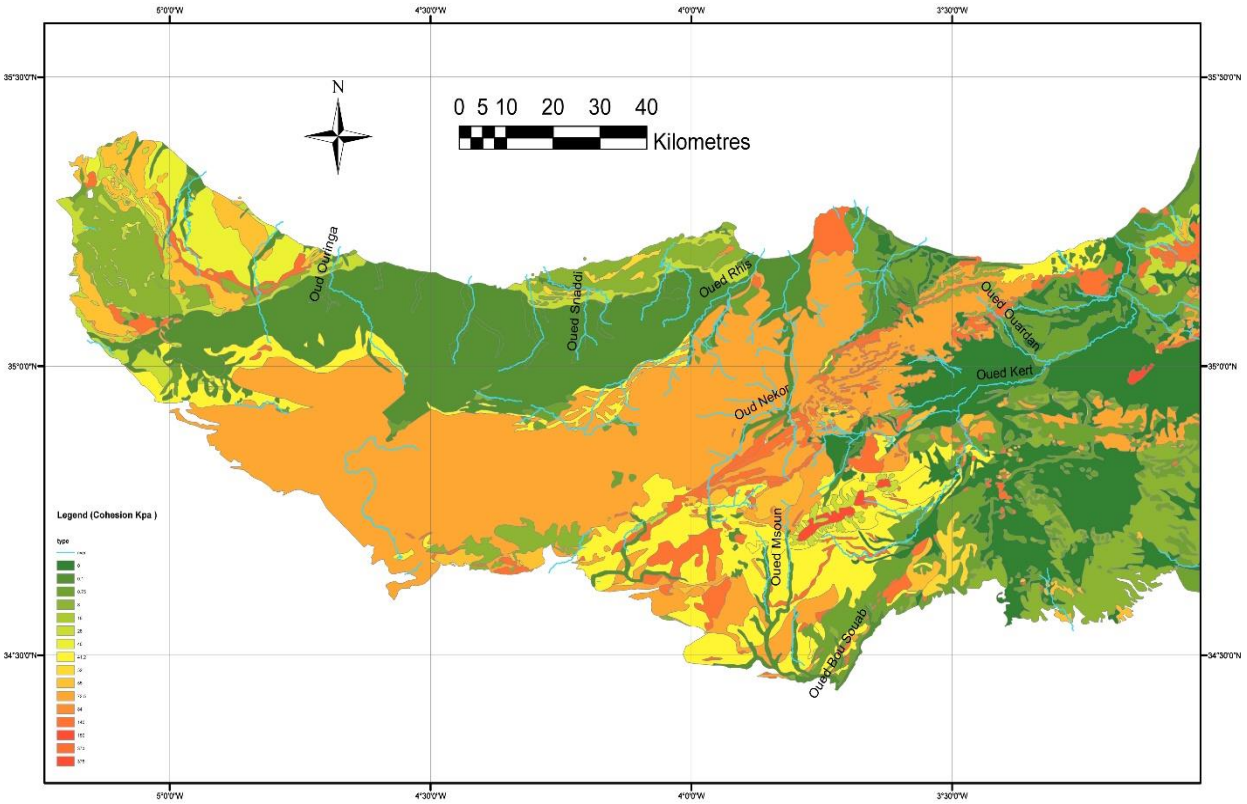

Figure 10 : ***Geotechnical maps (Cohesion in kPa) of Soils and Rocks in Al Hoceïma and El Jebha Region.***

b- Analysis and Discussion of geotechnical maps of Al Hoceïma and El Jebha

The analysis of geotechnical maps reveals the predominance of soils with low geotechnical characteristics, namely Schist, flysch, and marl, whose critical angles [26] for slip are low (66.67 % for Schist) compared to the high natural dip, as shown in the dip map (Fig.4). This is confirmed by the results of the following simulation (Fig.11) conducted on a homogeneous Schist slope (Table.1) with a height of 50 meters [27], using the Mohr-Coulomb [28] mechanical behavior model for soil behavior modeling and the bishop [29] method for calculating the safety factor [30] of the slop. This method involves dividing the slope into equal slices while considering inter-slice thrust forces.

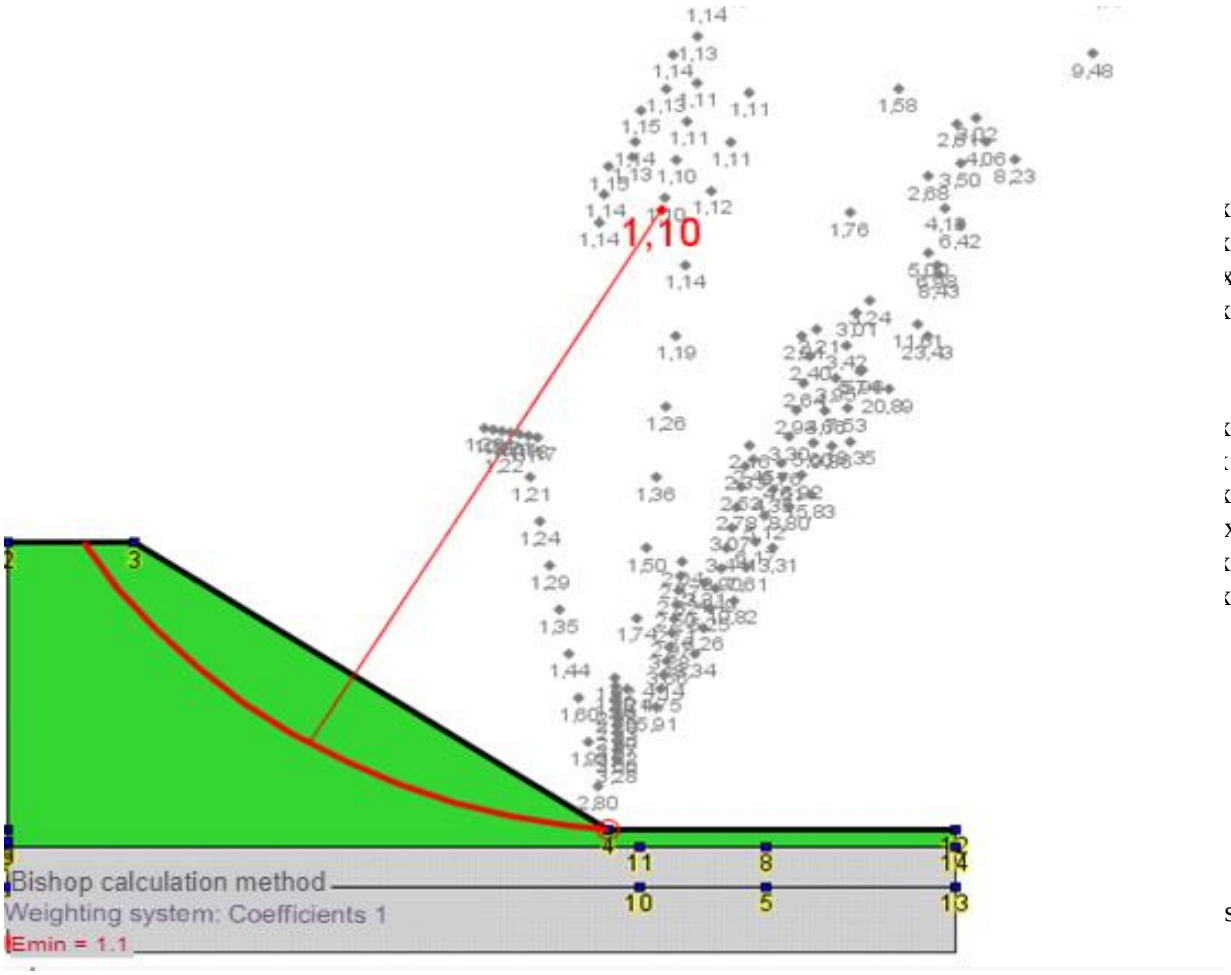

Figure 11 : ***Result of Simulation of Schist Slope Stability.***

As a conclusion, this work has led to the establishment of geotechnical maps describing the rheological parameters of soils and rocks in the study area, which did not previously exist for this region of the Middle Rif in the Kingdom of Morocco. These maps will allow us to geographically locate areas highly susceptible to landslides [32], by utilizing the data collected and presented in this article, including data on topographic dip, rainfall, and seismic activity. This information will be crucial for effective risk management and mitigation strategies in the region of Al Hoceïma and El Jebha.

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APPLICATION OF ELECTRICAL RESISTIVITY METHOD FOR PRE-CONSTRUCTION ASSESSMENT

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ABSTRACT

It is crucial to provide a proper picture of the nature of the subsurface for construction purposes. Electrical Resistivity Method (ERM) was employed to determine the subsurface competence of USM main campus using three survey profiles. Werner-Schlumberger array was selected for the subterraneous zones, layers, and depth values for the purpose of the construction on the study area. The results suggest that the studied subsurface consists of two major regions: loose sand and clay associated boulders as the unsaturated region and weathered/fracture region typically of granitic rocks, with resistivity values of 5 – 700 ohm.m, depth of 1.0 – 4.0 m; relative to deep saturated region. While the second region with resistivity values of 700 – 1300 ohm.m was interpreted to be weathered or unsaturated zones. The result of ERM determine the responses of the subsurface materials and properties by resistivity and depth values which provide insights for the stability of foundation at the construction site.

Key words: ERM, Clay, Foundation, Stability, Depth.

1.0 INTRODUCTION

The problem of any form of erected structures can be linked to either geotechnical deficiencies in the soil or insufficient subsurface analysis conducted prior to construction (Ilugbo et al., 2018, Bawallah et al., 2020). Differential settlements within weak layers, the presence of geologic cracks, such as faults, fractures, and shear zones beneath the infrastructure site, are among the causes (Oyedele et al., 2020).

Determining the bearing capacity of shallow geologic units, which are a component of a site's foundation design, is essential to ensuring the safety of people and property. Advancements in earth-imaging methods and data processing algorithms have greatly improved superficial and shallow site characterizations.

Electrical resistivity tomography (ERT) has become the most successful imaging technique among all the approaches for subsurface research and site characterizations. ERT offers subsurface geoengineering features and georesistivity characteristics of lithologic units (Storz et al., 2000; Akingboye et al., 2022). This work aims to estimate the two-dimensional (2D) ERT shallow models reflecting subsurface resistivity distribution, thickness, and depth of various layers of the research area at USM-Minden by the application of ERT for pre-construction assessment. The study is important because it advances our understanding of the subsurface and offers recommendations for environmental monitoring and infrastructure development.

2.0 LOCATION AND GEOLOGY OF THE STUDY AREA

The investigation was carried out on Penang Island (Figure 1), which is located in the northwest of Peninsular Malaysia along the Strait of Malacca at latitude 5.2228o N and longitude 100.1755o E. Similar to the Peninsular Malaysia's Central and Eastern belts, Penang State is part of the Western belt and exhibits distinct variations in stratigraphy, structure, magmatism, and geological development (Metcalfe, 2013). Three distinct

geological settings/formations regulate it geologically. The Simpang, Gula, and Beruas Formations are the names given to these structural settings or stratigraphy (Hassan, 1990). The lithological units that make up the Simpang Formation include clay, peat, sand, gravel, and, in some cases, silt. These units were deposited by alluvial progressions in the Pleistocene physical environment. In contrast, the Gula Formation has some shells as characteristics, but otherwise shares the same lithological units as the Simpang Formation. It is thought that throughout the Holocene epoch, these units were deposited in shallow marine, estuarine, and littoral environments. Finally, lithological units such as sand, gravel, clay, silt, and even peat that were deposited by a river system throughout the Holocene era are represented in the Beruas (Hassan, 1990).

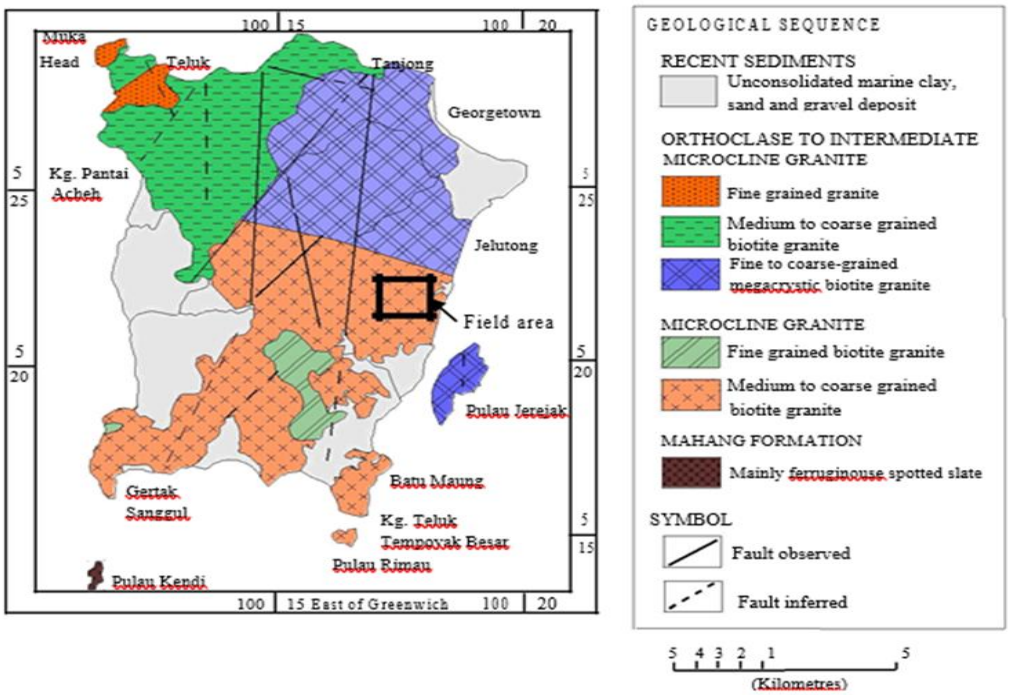

Figure 1: Geological map of Penang Island showing the study area (modified from Abdul Hamid *et al*., 2019)

3.0 METHODOLOGY

2D ERT was conducted at Main Campus of Universiti Sains Malaysia (USM) at Minden along three profiles with length of 20 m. The ABEM Terameter (SAS4000) was used to measure voltage for any set of four different planted electrodes selected at a time. The Wenner-Schlumberger array was adopted for its signal strength and horizontal resolution (Dahlin & Zhou, 2004). Two-reel cables, and 41 electrodes at 0.5 m spacing were set on the field. The system measured the lateral changes in resistivity with depth at the site.

4.0 ERT RESULTS AND DISCUSSION

The research region was divided into two main zones by the resistivity distribution of the soils (Figures 2, 3 and 4). In comparison to deep saturated zones, which are thought to be caused by fine-grained compacted soil, the first zone, which has resistivity values of 5 mΩ to 700 mΩ, is considered to be a saturated clayey sand region with a depth of 1.0 m to 4.0 m. In the meantime, the second region, which has values between 700 and 1300 mΩ, is thought to represent unsaturated or weathered zones connected to loose soil that is combined with stones close to the superficial cover.

There is a dry zone or zone of maximum resistivity made up of unsaturated clayey sand soil that is positioned at different points. There is also a zone of low resistivity made up of saturated clayey sand. Many elements, such as the random nature of the grain dimension, the extent of the aperture, and the height of saturation

(water), are likely to have an impact on the widespread electrical resistivity values of the subsurface (Al-Heety & Shanshal, 2016; Anukwu et al., 2020).

However, constrained lateral heterogeneity in resistivity values within the shallow surface materials is indicated by low resistivity values at different heights, which could be attributed to the presence of dry boulders with sizable dimensions and a rise in the amount of sand and clay in the mixture of soil units (Anukwu et al., 2020).

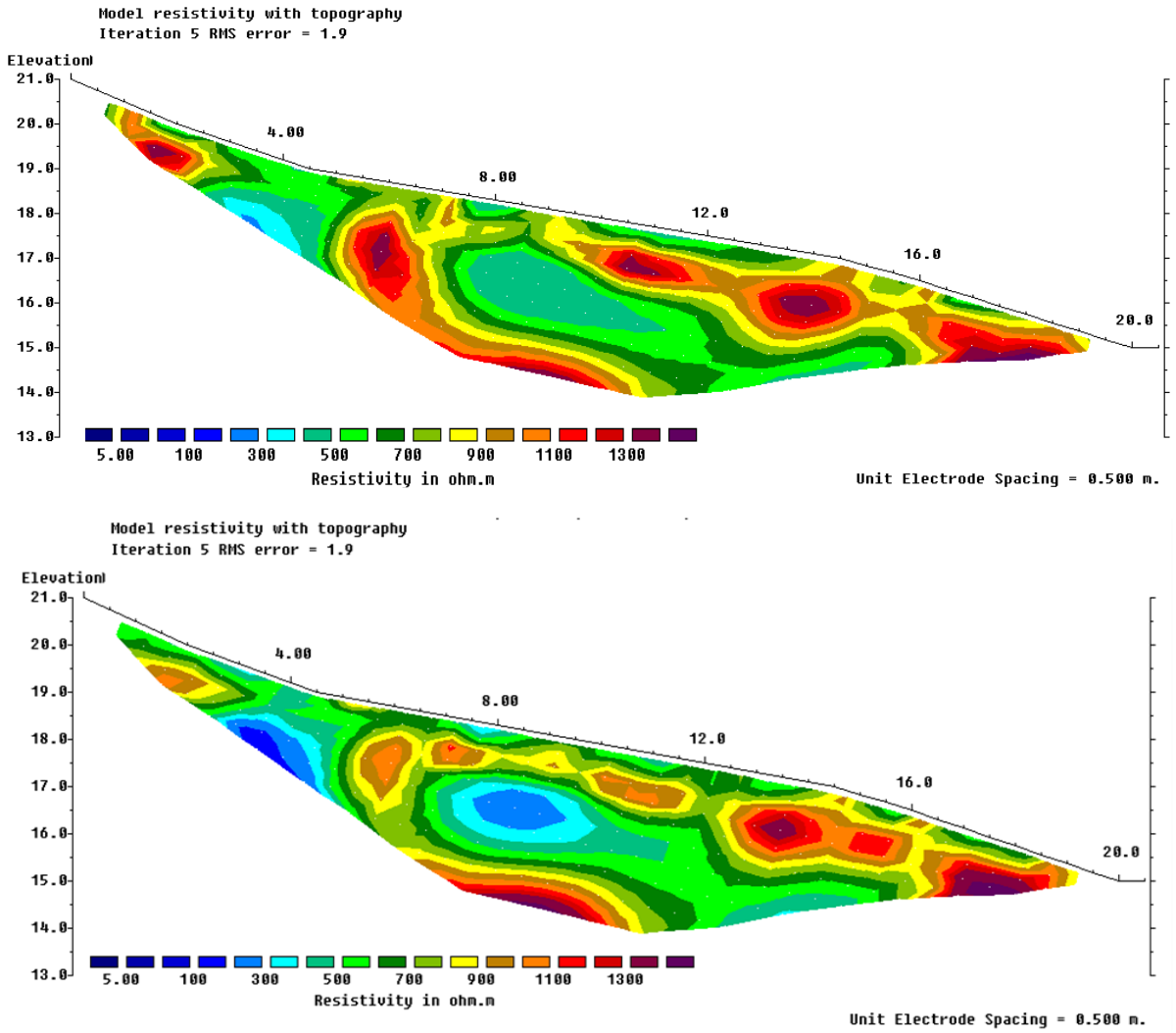

Figure 3: Model of ERT profile-2 at the study area

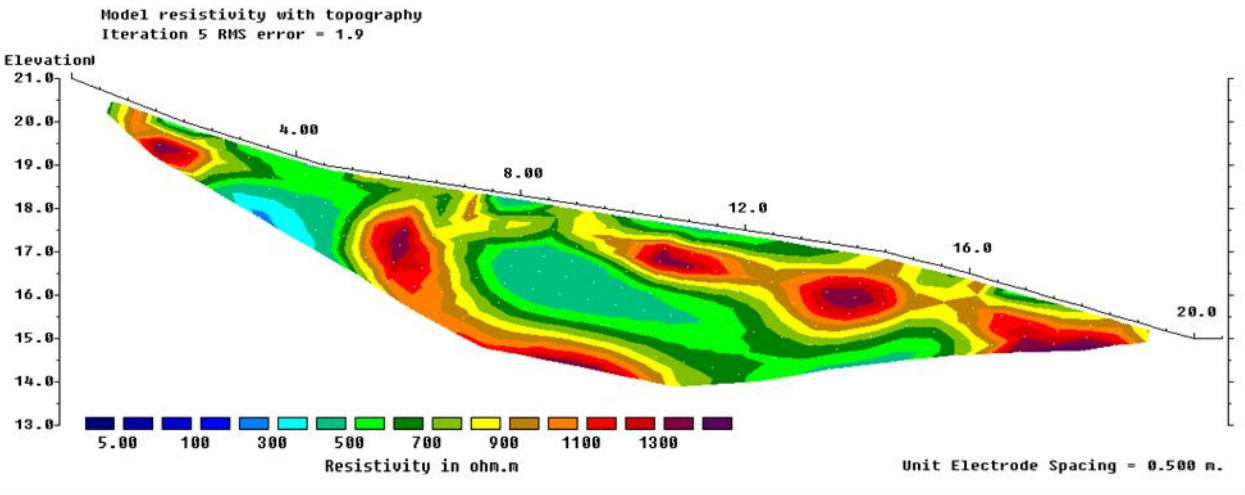

Figure 4: Model of ERT profile-3 at the study area

5.0 CONCLUSION

The ERT method has been successfully applied at the study area for uncovering more subsurface heterogeneity. The obtained results demonstrated and revealed more subsurface information and its variations, in terms of the electrical resistivity which can serve as the key to successful constructions of engineering/geotechnical projects.

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EFFECTS OF MONO-FLOR(CHLORINE)-SUBSTITUTION ON THE STRUCTURAL AND NON-LINEAR OPTICAL PROPERTIES OF POLY(3-HEXYLTHIOPHENE-2,5-DIYL) FOR SOLAR CELL APPLICATIONS

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ABSTRACT

Poly(3-hexylthiophene-2,5-diyl) (P3HT) and its derivatives are good organic semiconductors and have various applications in many fields such as photovoltaic systems, organic light-emitting diodes. In this study, the structural and nonlinear optical properties of P3HT were examined theoretically by dopping Chlorine and Fluorine to its structure. Gaussian 09 programs were used for calculations and GaussView programs were used for visuals. It was found that the bond lengths and bond angles of the isolated molecule were greater than the substituted P3HT. The band gap was calculated for fluorine-doped P3HT and chlorine-doped P3HT. Doped molecules were found to be more reactive than their isolated forms because they had lower chemical hardness values. Results on nonlinear optical (NLO) properties show that doped P3HT has good first-order hyperpolarizability. The open circuit voltage was also calculated. According to the results, the doped molecules have potential applications for photovoltaic devices due to good electron transfer.

Keywords: Photovoltaic, organic, P3HT, DFT.

Introduction

Some organic materials, such as conjugated polymers, organic semiconductors, organic small molecules (SMs), have properties that are flexible, lightweight, translucent and suitable for the fabrication of large-area devices (Khlaifia, Chemek, Alimi, 2020). Organic materials, especially based on conjugated polymers, have attracted the attention of many scientists due to their superior electrical and optical properties, reasonable chemical stability and easy processability. Polythiophene and its derivatives are considered one of the most promising conjugated polymers. Poly(3-hexylthiophene-2,5-diyl) (P3HT) and its derivatives are good organic semiconductors and have various applications in many fields such as photovoltaic systems, organic light-emitting diodes. (Shuwa, Said, Gidado, 2021; Franco Jr, 2020). Poly(3-hexylthiophene) (P3HT) molecule is an organic molecule that can be easily synthesized and can be used in solar cell applications thanks to its 1,5 eV band gap. Interestingly, many experimental and theoretical studies have been conducted on the synthesis and applications of P3HT and its derivatives (Sahu, Panda, 2013; Maillard, Rochefort, 2009; Gidado, Babaji, & Ado, 2015; Muhammad, Gidado, 2021; B Suleiman et al 2022)

Research showed that P3HT properties such as optoelectronic properties and crystallinity and its OSCs performance can be altered by modification of its end groups (Ramoroka et al 2020; Stuart et al 2013; Ndikilar et al 2022). In this study, the structural and nonlinear optical properties of P3HT were examined theoretically by adding Chlorine and Fluorine to its structure.

Materials and Methods

All computations were carried out using windows version of Gaussian 09W (Frisch et al 2009) software package and Gauss View, Rev 5.0.9 (Denington, 2009) molecular visualization tool. The Density Functional Theory (DFT) calculations were performed using Becke's three-parameter hybrid functional with the Lee-

Yang-Parr correlation functional, a combination that "gives rise to the well-known B3LYP method (Chai, Head-Gordon, 2008).

Findings and Discussion

The initial molecular geometry of the compound [(C10H14S)n] was determined using Gauss-View. We found the geometry optimization energy values (E) for Isolated, Chlorine and Fluorine as -45034 eV, -57552 eV and -47728 eV, respectively. According to these values, the chlorinated structure is more stable than the others because it has the lowest energy.

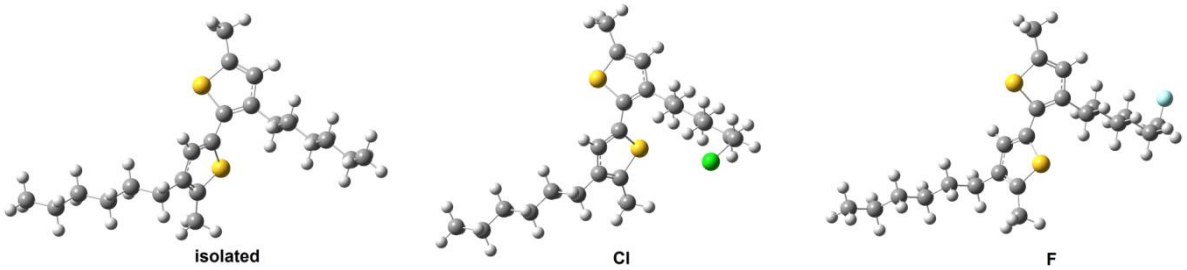

Figure1. Optimized theoretical structures: isolated, chlorine and fluorine doped.

In electronic properties, the energy difference between HOMO (highest occupied molecular orbital) and LUMO (lowest unoccupied molecular orbital) gives us information about the stability of the molecule. The energy gap is a critical parameter in determining molecular electri- cal transport properties (Evecen et al 2023). If an electronic system has a larger HOMO-LUMO energy difference (Egap), it will be less reactive than an electronic system with a smaller gap. olur.The energy gaps (Egap) is calculated 4,697 for isolated, 4,65 for Cl and 4,602 eV for F. Accordingly, the F structure is more reactive than the others.

I is the ionization potential, A is the electron affinity, χ is electronegativity. As the difference in electronic chemical potential (μ) increases, the global electron density transfer will have a less polar character. The resistance of a molecule to changing electron density with the environment is defined as chemical hardness (η). Molecules with high chemical hardness values have little or no intramolecular charge transfer. A large HOMO-LUMO gap (ΔE_{H-L}) indicates a harder molecule, a small ΔEH-L indicates a softer molecule. It is possible to relate the stability of the molecule to η; This means that the molecule with the least ΔE_{H-L} is more reactive and less stable. A high value of the electrophilicity index w indicates that the molecule is highly stable and dye solutions containing this molecule have higher resistance to fading when exposed to light; this is a property known as lightfastness.

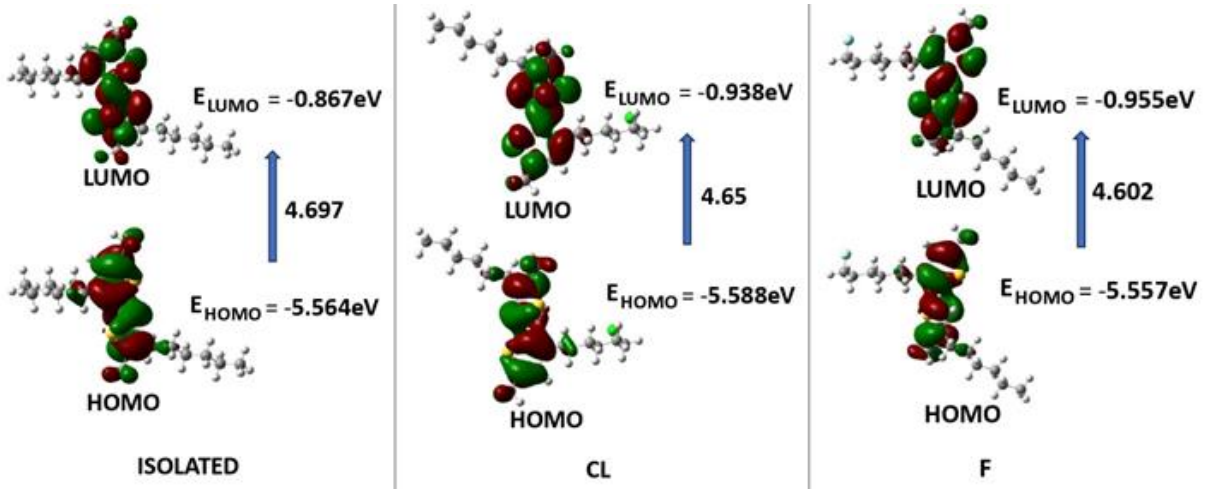

Figure 2. FMO analyzes

Table 1. Electronic Parameters

Parameters (eV)	isolated	Cl	F
E_{HOMO}	-5,564	-5,588	-5,557
E_{LUMO}	-0,867	-0,938	-0,955
$\Delta E = E_{LUMO}-E_{HOMO}$	4,697	4,65	4,602
$I = -E_{HOMO}$	5,564	5,588	5,557
$A = -E_{LUMO}$	0,867	0,938	0,955
$\chi = (I+A)/2$	3,215	3,263	3,256
$\mu=-\chi$	-3,215	-3,263	-3,256
$w= \mu 2/2\eta$	2,201	2,289	2,303
$\eta = (I-A)/2$	2,348	2,325	2,301
$S = 1/2\eta$	0.213	0,215	0,217

The study of nonlinear optics (NLO) has been in the focus of collaborative research due to its wide application in the fields of data storage technology, signal processing, laser technology, optical communications and optical interconnect . DFT is widely used as an effective method to investigate organic NLO materials (Powel et al 2004). Here we investigated the nonlinear optical properties of whole molecules using B3LYP. Superior values of dipole moment, molecular polarization and hyperpolarization ability are required for a molecule to act as a better NLO material. The dipole moment (μ) of a molecule gives information about the charge distribution and geometry of the molecule. μ, α and β are listed in Table 2.

Table 2. The dipol moment, polarisability and first hyperpolarizability values.

Dipol	isolated	Cl	F		isolated	Cl	F
μ_x	0,0466	-0,7338	-1,2016	**HyperPol.**			
μ_y	-0,4497	1,2038	-1,3839	β_{xxx}	57,94	76,97	32,99
μ_z	-0,4652	0,9010	0,4603	β_{xxy}	25,72	97,07	30,16
μ_T	**0.6487**	**1.6731**	**1.8897**	β_{xyy}	-46,91	-37,61	-45,15
Polar				β_{yyy}	37,87	55,59	0,03
α_{xx}	352,11	347,89	351,85	β_{xxz}	-17,48	-40,04	49,18
α_{xy}	25,82	39,99	32,84	β_{xyz}	40,85	22,72	-25,55
α_{yy}	299,85	309,86	301,51	β_{yyz}	8,423	36,35	-9,04
α_{xz}	-1,41	-8,37	7,31	β_{xzz}	-11,18	15,53	-26,30
α_{yz}	30,42	30,89	-33,53	β_{yzz}	-23,28	13,60	-39,82
α_{zz}	241,34	263,92	241,50	β_{zzz}	-60,51	-100,12	75,60
α_T	**44,08**	**45,48**	**44,16**	β_T	**6,9469E-31**	**17,5884E-31**	**10,572E-31**

Urea is a prototypical molecule in the study of NLO properties and is therefore frequently used in comparative studies. The μ and α values calculated for the molecule are listed in Table 2. These are larger than those of urea (μ = 1,3732 Debye, α = 3,8312 $Å^3$). As obtained by method B3LYP/6-31G(d). It is observed from the table that there is an increase in values of μ, α and β due to the effects of the substitutions (Ndikilar et al 2022). In other words, doped Cl and F P3HT molecules show greater NLO properties than the isolated P3HT.

β values calculated for the molecule: As seen Table 2: β_T =6,9469E-31 (isolated); β_T =17,5884E-31 (Cl) and β_T =10,572E-31 (Flore). All β values are greater than that of urea (β_{ure} = 3,7289×10^{-31} cm^5/esu, obtained by B3LYP/6-31G(d)) method). The magnitude of polarizability and hyperpolarizability is important for the NLO system. As seen in the table, the doped Cl and F values are greater than the isolated molecule. As a result, all molecules are good candidates for NLO materials.

Conclusion and Recommendations

The isolated and doped P3HT compound was examined by the DFT method. HOMO and LUMO energies were calculated for fluorine-doped P3HT and chlorine-doped P3HT. Doped molecules were found to be more reactive than their isolated forms because they had lower chemical hardness values. Frontier Molecular Orbital values were calculated. Results on NLO properties showed that doped P3HT has good first-order hyperpolarizability. According to the results, doped molecules may have potential applications for optical and photovoltaic devices due to their good electron transfer.

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ENERGY AVAILABILITY ANALYSIS OF TRAKYA REGION COALS WITH NEW GENERATION TECHNOLOGIES

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ABSTRACT

In recent years, global and regional crises that threaten energy supply security have forced countries to turn to domestic coal resources, almost forgetting and disregarding the Paris climate agreement and its related obligations. Coal continues to lead the world in energy resources with a share of 35.72% in 2022.

Coal reserves in the Thrace Region part of Türkiye (Trakya), on the other hand, draw attention as a domestic coal-based energy source for Thrace in the short term with the increasing geopolitical and geostrategic importance of the region due to its identity as a central energy transit corridor (energy hub). The coal reserve of the region, which has reached 3.27 billion tons with the increases in the last two decades, has been analysed and evaluated numerically within the scope of this research with a integrated approach in the process from coal production to clean energy generation.

Based on numerical analyses and evaluations; it is understood that Edirne-Uzunköprü- Harmanlı coals, which are a solid and domestic alternative to imported natural gas, which reaches approximately 80% in energy, are an indispensable domestic energy source in energy. The reserves in the region have the potential to be transformed to energy in the short term in high-efficiency supercritical (SC) or ultra-supercritical (USC) thermal power plants with total power ranging from 400-2000 MW, and in the long term through new generation underground (UCG) and aboveground gasification (IGCC) technologies. Especially with the mechanization process in underground coal production in Edirne-Uzunköprü-Harmanlı, the first and pioneering one in the region in 2019, coal production rates (P>1.5-2 million tons/year) have been reached to feed thermal power plants equipped with such new generation energy technologies. Therefore, Thrace region has contributed to the growth of the industrial-production index of the region with the transition to the large-scale operation model created in the coal sector and the accompanying labour employment. In addition, it was concluded that the coal of Edirne-Uzunköprü Harmanlı Region, which is classified as Oligocene aged sub-bituminous-A and contains high volatile matter, can easily compete with imported bituminous coals in the domestic and foreign markets with its total sulphur S= 0.24-0.5% and lower heating value LHV= 5150-5726 kcal/kg on dry basis, but for this purpose, the coals of this region must be "*registered*".

Keywords: Türkiye's Thrace Region- Edirne-Uzunköprü- Harmanlı, Sub-bituminous coal, Thermal power plant and gasification, Energy and environment.

1. Introduction

Global energy crises have brought attention to all countries with the capacity to increase the utilization of domestic coal resources and to the next generation of coal-based technologies. Globally, coal has more reserves and a more equitable geological distribution than other fossil fuels such as oil and natural gas. Coal continues to stand out as an "energy anti-crisis" resource in global and regional energy crises that threaten energy supply security and in the risk management of energy-based emergency action plans.

In 2022, world total coal reserves are 1.07 trillion tons, with a total production of 8.687 billion tons/year. Coal reserves significantly exceed oil and gas reserves, estimates of total world coal resources (including un-minable coal) are often expressed in trillions of tons rather than billions, and recent studies estimate the world's remaining coal resources at 18 trillion tons (Cough, 2009).

The Russian-Ukrainian war, which started in 2022, has seriously jeopardized the security of energy supply on a global basis and has dealt a blow to the idea that global coal demand may soon decline. The Russian-Ukrainian war, which started in 2022, has seriously jeopardized the security of energy supply on a global basis and has dealt a blow to the idea that global coal demand may soon decline. The decline in coal demand in 2020 was more than compensated by the strong recovery in 2021, with demand for coal close to an all-time high. It is reported that demand increased by 10% in advanced economies, where coal use is declining, and by 5% in emerging economies, which share just over 80% of global coal use (IEA, 2022).

Clean combustion and pollutant gas removal technologies are one of the ways to eliminate the emission of pollutant gases during the conversion of coal, a combustible organic sedimentary rock, into energy. These technologies, including supercritical and ultra-supercritical combustion technologies with efficiencies ranging between 35% and 50%, underground gasification (UCG) and above ground gasification (IGCC) and liquefaction technologies, are called new generation clean coal technologies, which are widely used in the world but have limited use in our country (WEC-DEKTMK, 2010).

In particular, by underground gasification (UCG) technology, coal can be burned in-situ, without mined, acting as a geo-reactor. UCG is essentially a combination of mining methods, it is a form of operation through gasification that eliminates the need for mining and can be used in deep or steep seam coal seams that cannot be mined. Although it is seen as a promising option for future use, it is noted that commercialization on a large scale will take time and require significant investment (Couch, 2009; Bhutto et al., 2013). Most existing coal gasification technologies, such as entrained flow, fluidized bed and moving bed, use a surface reactor for gasification.

Thrace Region-Uzunköprü Harmanlı coals, deposited in the Oligocene aged Danismen Formation, are classified as sub-bituminous-A with high volatile matter (Şengüler et al., 2000; MTA, 2002; Tokgöz, 2005; Şengüler, 2015; MTA, 2020; Çelik el al., 2017; Karayiğit el al., 2021; Tokgöz, 2023). The coals of the region are thin-seamed (1.10-1.70 m) coals with different geological formations, with calorific value of 5200-5750 kcal/kg and with low total sulfur content of 0.20-0.50% (Tokgöz, 2023). With these coal quality characteristics, Uzunköprü Harmanlı region coals are at a level that can compete with imported coals, even though they are sub-bituminous coals (Tokgöz, 2023).

This study gives a brief outlook of Thrace Region's coal assets in terms of energy resources and energy policies on global, regional and local basis, and will reveal the place and importance of Thrace Region and Edirne-Uzunköprü- Harmanlı coals in energy in terms of the country and the region. Then, numerical analyses and evaluations are made with a integrated perspective covering *"energy-economy-environment"* approach, taking into account coal quality characteristics, domestic and foreign market shares in consumption areas. Also, a brief cost analysis was given considering clean coal technologies and in-situ gasification technologies in the new generation environmental friendly thermal power plants for the energy conversion processes of the region's coals. Thereby, the importance of Thrace's coal resources in terms of industry and environment has been highlighted.

2. A Brief Outlook of the Role and Importance of Coal as an Energy Source on Global, Regional and Local Scale

In order to evaluate the position and importance of coal in the energy sector in the Thrace Region from a quantitative perspective, a comprehensive analysis focusing on coal and other energy resources used in the world in general, in Turkey in particular, in the Thrace Region and especially in Edirne-Uzunköprü-Harmanlı locality has been carried out. In these analyses, the effects of the global energy crises that occurred in the period from 1973 to the present day have also been analyzed based on the data range between 1970 and 2022, and the evaluations are presented below.

2.1. The role and importance of coal in global energy generation

Global energy crises are major factors affecting the dynamics of the coal-based energy sector. These crises sometimes present opportunities besides their challenges, especially in determining and directing coal-based energy policies and strategies. Indeed, one of these crises is the Russia-Ukraine war in early 2022. Numerical

analysis and assessment of crisis the impacts of which will be evident in 2023 and later, is presented in Figure 1. A careful examination of the figure indicates the following important finding and evaluations:

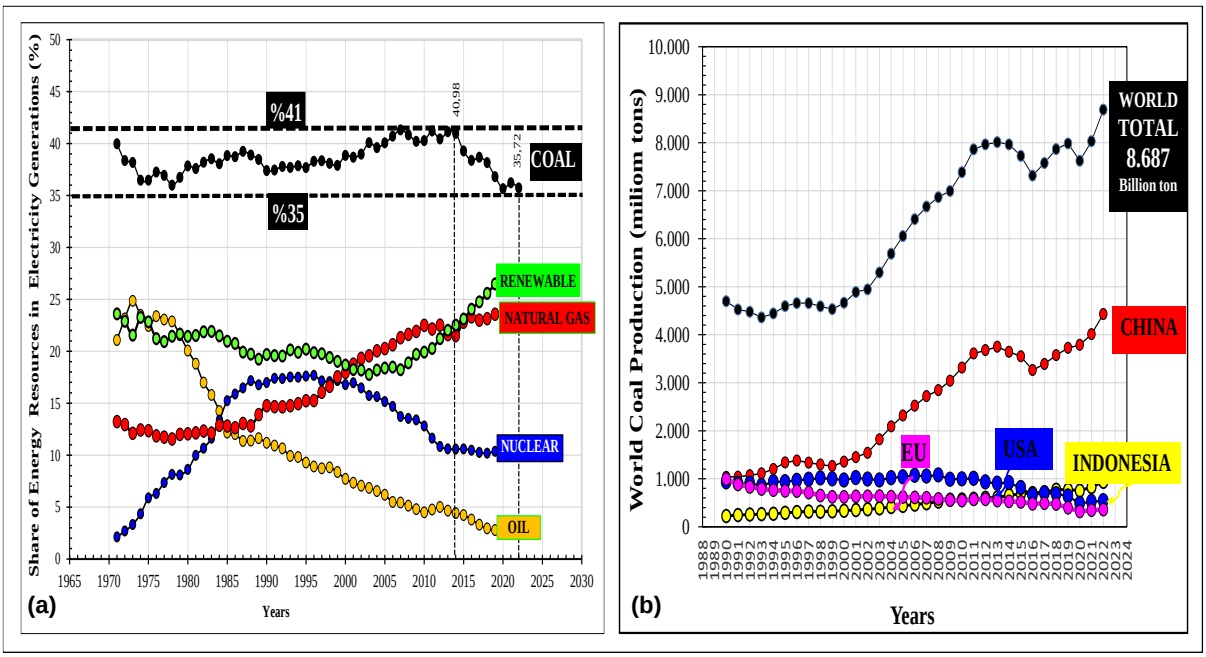

Figure 1. (a)World electricity generation share of coal in other energy sources in 1971-2022, (b) Major coal producing countries in the world (Tokgöz, 2023).

- In 2022, the world's total coal reserves are 1.07 trillion tons, with a production of 8.687 billion tons/year. Coal continues to lead the energy resources with a share of 35.72% in 2022.
- Increasing energy supply security risks indicate that the share of coal in energy, which

was 35.72% in 2022, may increase in the range of 35-41% in future crises (Figure 1a) (Tokgöz, 2012; Tokgöz, 2023).

- With the Ukraine-Russia war seriously threatening coal supply security and coal prices remaining high, world coal production increased by 8.2% to 8.687 billion tons in 2022. In the European Union, disruptions in natural gas supply and price increases have led to the need to increase coal-based production in the short term. Against this backdrop, coal power plant activities are likely to intensify across Europe in the coming period. For example, it is reported that Germany, a member of the European Union, has almost made a "U-turn" to coal, in other words, by focusing on coal-fired power plants to meet its natural gas-based energy deficit (EIA, 2023).
- The situation in the coal-producing countries of Central Asia, which holds more than 70% of coal production, has become even more apparent, increasing by 11% in 2022. China, which signed the Paris climate agreement in 2022, produces 4.43 billion tons (2022), which is the sum of Thrace coal (3.27 billion tons) and Istanbul Silivri-Sinekli coal (1.16 billion tons) in one year (Figure 1b) (Tokgöz, 2023). With this level of production, China continues to be a "global leading actor in energy and emissions" by determining coal production and consumption trends in the world.
- In the long term, the process of switching to alternative sources and renewable energy has started to gain acceleration with a polynomial increase. To summarize, the global shift towards 25-30% resource diversity in energy can be seen as a necessity for countries' energy supply security as well as their Paris climate agreement reduction obligations.

2.2. The role and importance of coal in Turkey's energy production

Turkey's energy production was analyzed in the period of 1971-2022 according to installed capacity and share of resources (Figure 2) (Tokgöz, 2023). Beginning with the oil crisis in 1973 and continuing with the Russia-Ukraine war in 2022, the 5-6 global crises experienced during this period increased the share of coal and water as domestic resources in energy production. In 1985, the dependence on imported resources, which started with the import of natural gas, increased rapidly and dragged Turkey into wrong and alienated energy policies, especially with "*take-or-pay"* agreements. After reaching nearly 50% in 2008 and 2009, this import dependency in natural gas decreased to 18.9% in 2019 with the decline that started in 2009, and continued its gradual decline, eventually reached 33.2% again with the 2020-2021 pandemic. In 2022, the share of natural gas in energy resources fell again to 22%. In 2019, the declining share of natural gas was compensated by 14.7% in renewable energy, 29.2% in hydroelectricity and 37.1% in coal (imported + domestic), and the late move towards *"resource diversity"* in energy became evident. However, it is noteworthy that not all of the 34% share of coal in energy is domestic coal, 19% of which is imported hard coal. This clearly shows that the decreasing dependence on foreign resources in energy, which was also decreasing in natural gas, is now balanced with hard coal and imported resource dependence is continued (Figure 2a).

Concerning the situation of renewable energy in Turkey, it is observed that the polynomial increases in the world's leading countries in this regard are increasing with a similar trend in Turkey, but after 2016, Turkey has exhibited a steeper and faster numerical increase (exponential) in order to reach the EU's 26.5% share in a short time, leaving China and the USA behind (Figure 3) (Tokgöz, 2023). This increase is considered as a shift towards "*resource diversification*" with renewable resources as a mandatory consequence of the Paris agreement and its related obligations.

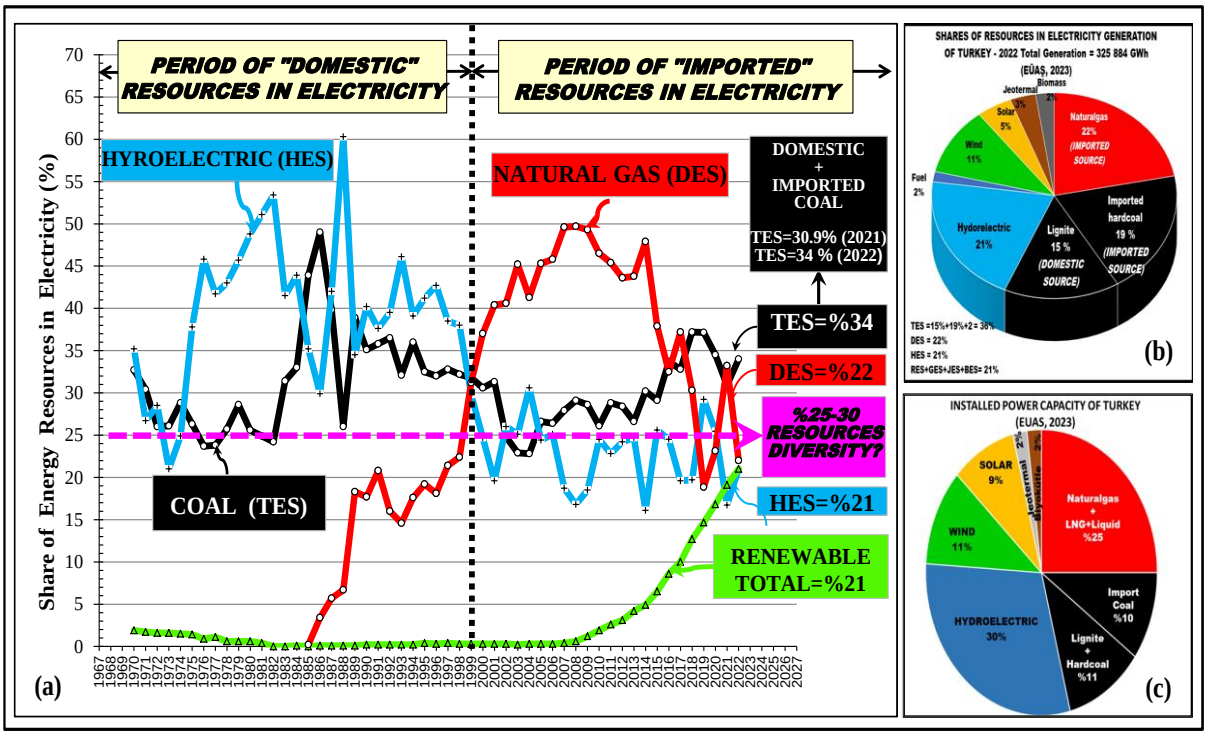

Figure 2. (a) % change in Turkey's electricity generation by energy sources for the period 1970-2022 (b) Distribution of electricity generation by sources in 2022 (%), c) Installed capacity of thermal power plants (Numerical raw data taken from TEIAŞ, 2022 and EÜAŞ, 2023) (Tokgöz, 2023).

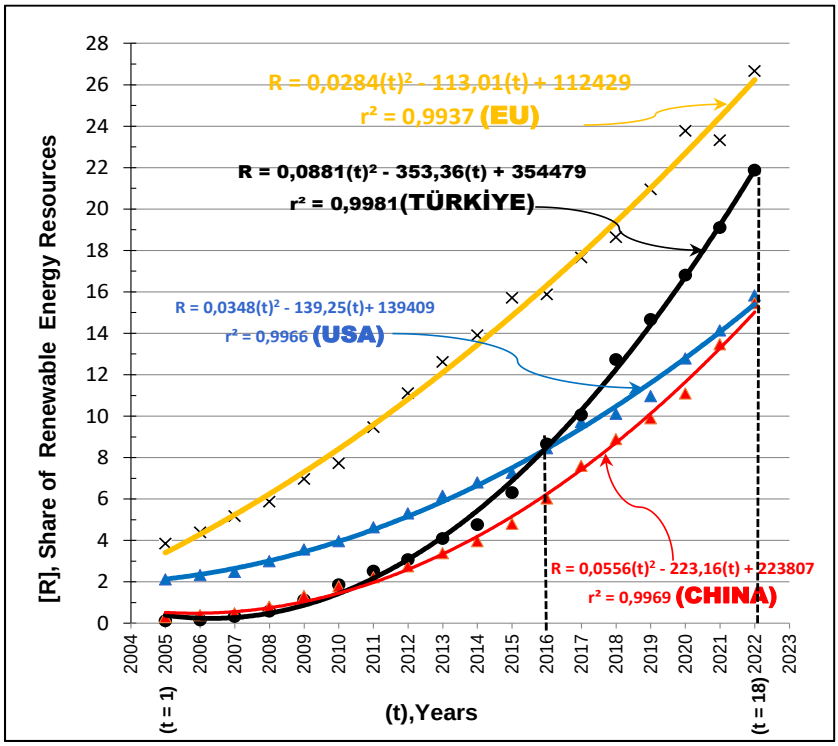

Figure 3. Analysis of increasing trends in renewable energy for some countries (Tokgöz, 2023).

2.3. The role and importance of coal in Thrace's energy production

The energy needs of Thrace are met by imported natural gas with a 76% share, wind with 22%, solar and biofuels with 1% each, and renewable energy sources with a total of 24% (Figure 4). The energy consumption of the Thrace region in 2022 was 12.52 billion kWh. In the 2030 projection performed within the scope of this research, the calculated or estimated (predicted) electricity energy consumption was determined as 21.30 - 24.80 billion kWh (Figure 5) (Tokgöz, 2023).

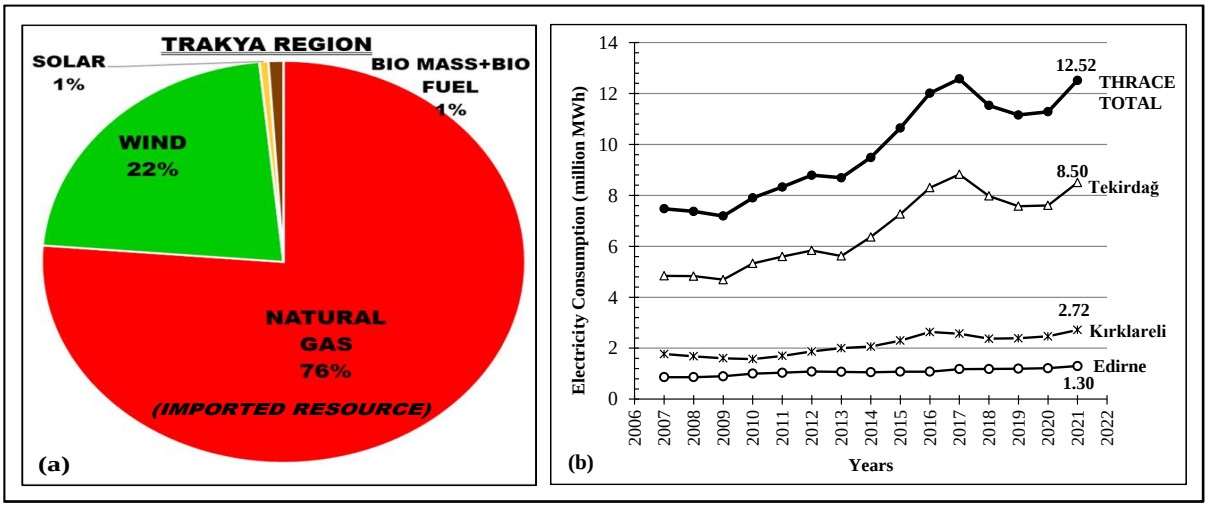

Figure 4. (a) Distribution of Thrace's energy installed capacity by source in 2022, (b) 2007-2021 period electricity consumption in Thrace

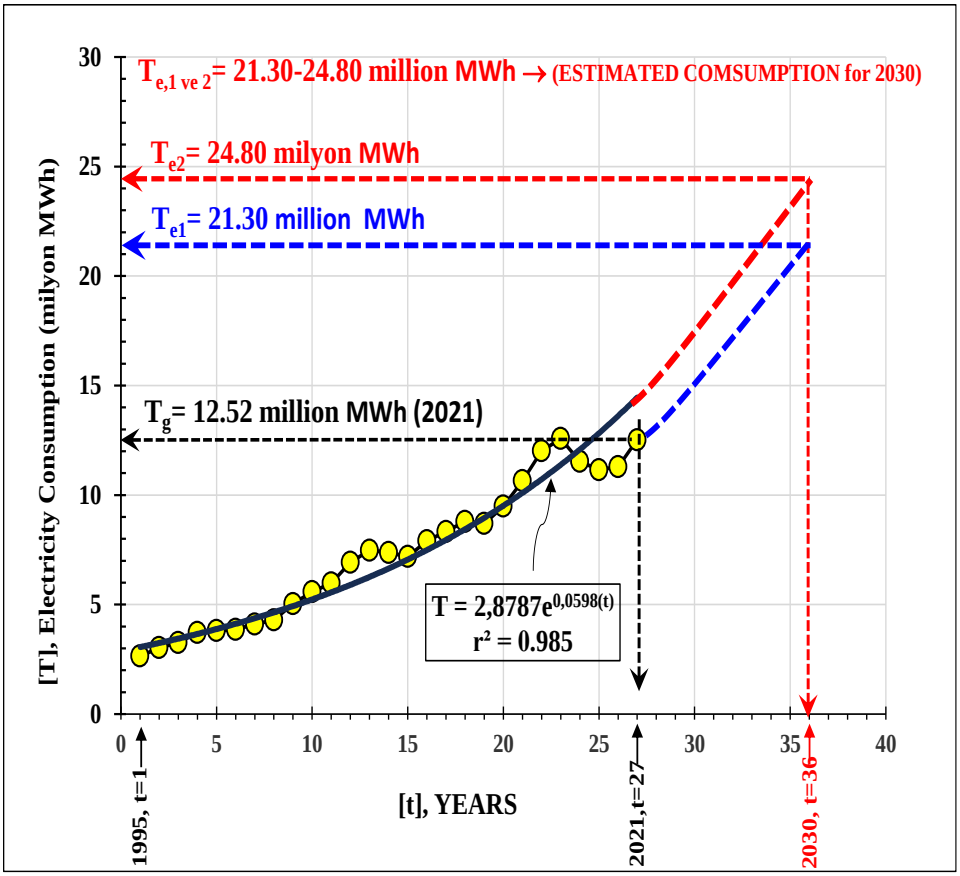

Figure 5. Thrace's electric energy consumption for the period 1995-2021 and estimated consumption for 2030. (Tokgöz, 2023).

3. Thrace Region Coal Reserves and Coal Quality Characteristics Analysis and Evaluation

3.1. Analysis of Thrace region coals according to their reserves, current production scale and technology

While the total coal reserve of the Thrace Region was 330 million tons in the 2000s (Figure 6a (Tokgöz, 2005), with the ongoing exploration activities by MTA in 2005 and afterwards, a total reserve of 3.27 billion tons was reached in 2022 (Figure 6b) with an increase of approximately 9-10 times (MTA, 2022). Thrace Region has a high share of 16% of Turkey's total coal reserves of 20.4 billion tons. When Istanbul Silivri-Sinekli coal reserves (1.16 billion tons) are included to reserve of Thrace, a total reserve of 4.43 billion tons is reached in the north of Marmara.

Thrace Uzunköprü-Harmanlı coals located in the southwestern part of the region were examined within the scope of this study and their total reserves are reported as 140 million tons (MTA, 2022). The distribution of operating licenses of Oligocene aged and high volatile sub-bituminous coals in the region is located in the southwest direction. The coals in the region are generally thin seam (1.10-1.70m) and two coal seams with different geological formations are produced by fully mechanized underground longwall mining method and excavation at a single excavation height of 3.5 m (Yazıcı, et al., 2023). Together with this fully mechanized underground operation, in 2022, a total of 93 small and medium-sized open-pit and underground coal operations were operating throughout the region.

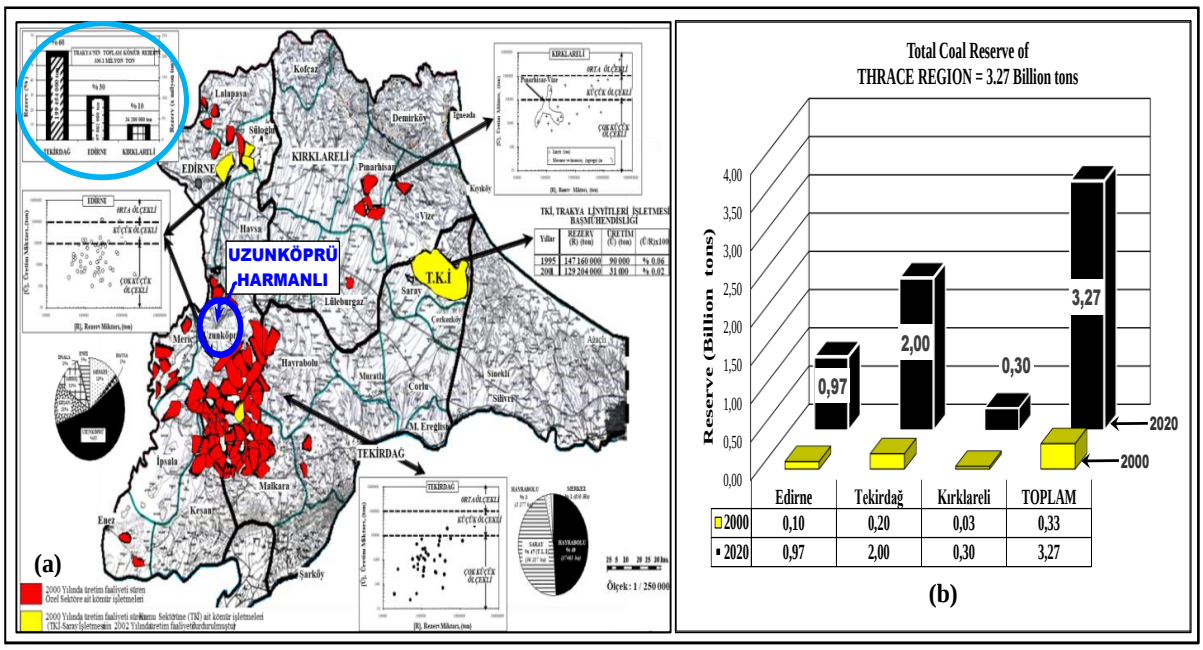

Figure 6. Distribution of Thrace Region reserves a) in 2000 (Tokgöz, 2005) b) in 2022.

When Figure 6 is carefully examined, it is seen that the production capacities of the coal mines operating in the northern and western of the Thrace region are in the production scale of "*very small-small scale*" coal mines such as P=10 000-100 000 tons/year (Tokgöz, 2005). The rationalization movement achieved with full mechanization in a privately owned underground coal mine in Edirne-Uzunköprü-Harmanlı in 2019-2020 is a precedent setting process in the region, especially in the data range covering the years 2000-2020. Significant investments and technological improvements in excavation and production technology during this period brought about a significant evolution in coal production in Thrace coal mining. Compared to traditional classical and primitive production methods, a more effective and efficient production model was adopted and occupational safety standards were improved. By 2020-2023, the low actual production capacities of the previous years were increased by approximately 15-20 times with the full mechanization applied and the capacities increased to P=1.5-2.0 million tons/year, thus enabling the coal mines to adopt a sustainable underground production practice. The amount of mechanization and rationalization investment in the Thrace Region is reported to be approximately 60-70 million dollars (Yazıcı, et al., 2023). With such significant investments, modernization of underground coal mine operations is accelerated and more efficient production practices as well as occupational safety processes are improved by installing automation and mechanization systems with high-tech equipment. With this development, the region can gain a competitive advantage in coal-based industrial production that reaches international standards. Moreover, by increasing the region's growth potential in the energy sector, the technical equipment and know-how required to design a new generation zero-emission thermal power plant can be achieved in this way.

3.2. Analysis of Uzunköprü Harmanlı coals according to coal quality characteristics

In order to analyze the coal quality characteristics of low bituminous and high volatile Harmanlı coals, block samples were taken from 130 m depth underground. Core samples were taken from these block samples and the physical, mechanical and coal quality characteristics of the coals were determined. Laboratory measurements included proximate and ultimate analysis, calorimetric analysis and grindability (hard grove) index. The data obtained from these analyses, in which 3 measurements were repeated from each sample, were evaluated by regression analysis and their numerical relationships with other characteristic quantities that determine and affect the lower heating value of coal were investigated. The analyses conducted by MTA in 2002 for this area were also included in this evaluation as raw data. In addition, in order to investigate the competitiveness of Harmanlı coal in foreign markets, samples from 3 different imported coals (Siberia, Iran and South Africa) were taken and analyzed in the laboratory. The study on this subject is presented in Figure 7.

- *Proximate analysis (M= 6-10%, A=4-11%, VM=38-42%, FC=38-52)*
- *Ultimate analysis (elemental) (C_e= 58-65%, =1.39-1.55%, H_e= 5.31-5.63%, S=0.24-0.50%) (C_e ,N_e ,H_e = Elemental compounds of carbon, nitrogen and hydrogen, in respectively).*

The following findings and evaluations were obtained from the analysis in Figure 7.

- The total sulfur content of Uzunköprü-Harmanlı coals was determined as S=0.3 % and this value is S=1.13% for Siberian coals, S=1.30% for Iran's coals and S=0.20 % for South African coals. Uzunköprü-Harmanlı coal has low total sulphur content that can compete with imported coals.
- The lower heating value for Harmanlı coal was measured between 5250 and 6420 kcal/kg in dry base. Mean value is 5726 kcal/kg (*24MJ/kg*). In original base, the LHV= 5150 kcal/kg (*21.6 MJ/kg*) was measured. Although the Harmanlı coals are sub bituminous coal, it can be competed the bituminous of imported coals.
- As for the moisture and ash contents, it is clearly observed that Harmanlı coal is in consistence with these values of the three imported coal.
- Since Harmanlı coal is sub-bituminous coal, its volatile matter is higher than the bituminous coals of imported coals. This situation caused decreases in the lower calorific value.
- The Hargrove Grindability Index for Harmanlı coal was varied between 39 and 48. Mean value is HGI=44.

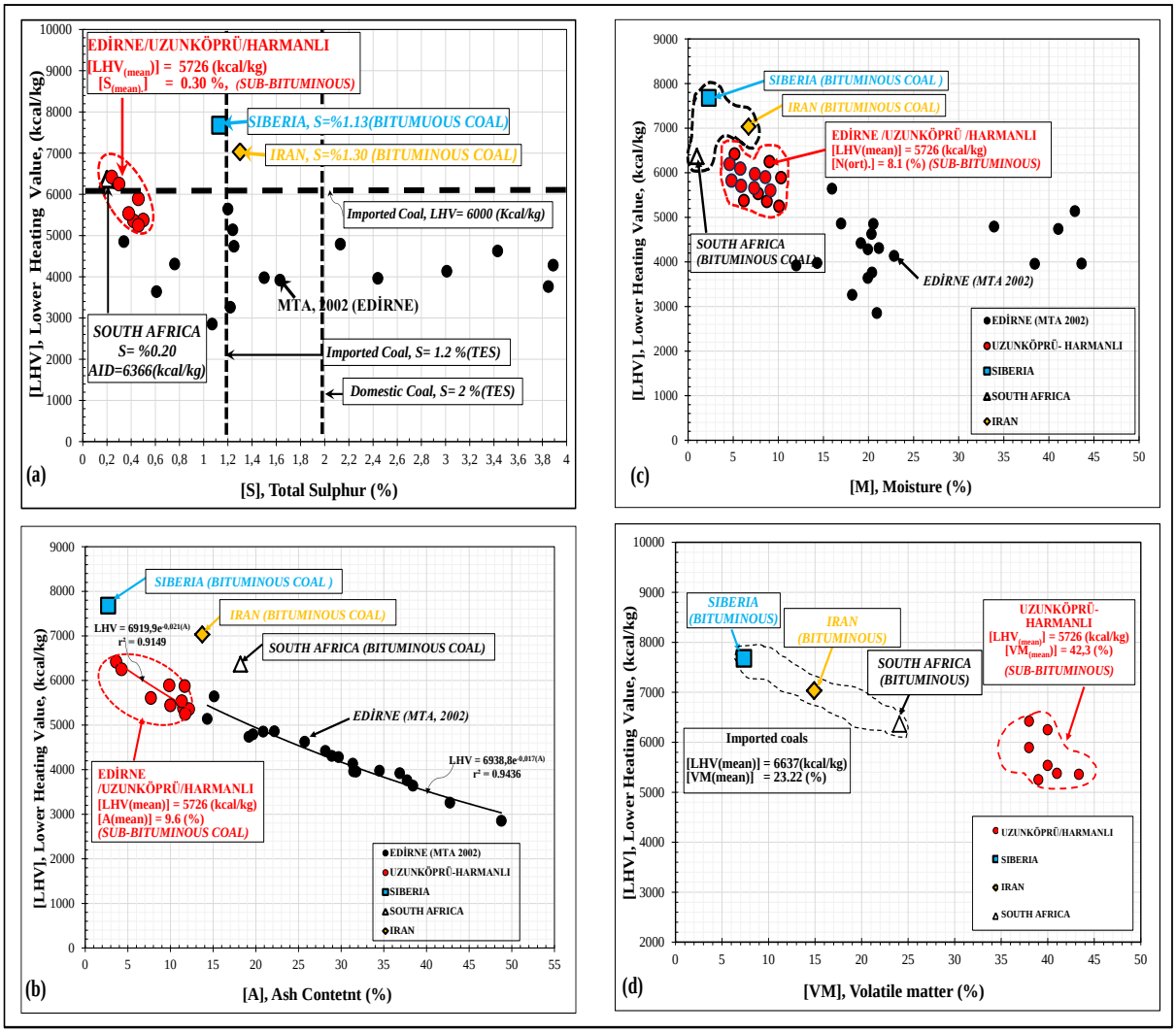

Figure 7. Coal quality characteristics of Uzunköprü - Harmanlı coals.

4. An Outlook Energy Technologies in Türkiye with Coal based-Thermal Power Plants

In Turkey, coal-fired thermal power plants are operated with a low capacity factor of 50-55% from time to time and there are extensive studies examining the reasons for this (Aytaç, 2017; MMO, 2023). This study analyzed the capacity factor and dynamic age of total 24 imported and domestic coal-fired thermal power plants in Turkey with a capacity of more than 200 MW and reached the following findings and evaluations (Figure 8).

Of the total 24 thermal power plants above 200 MW, 16 (67%) have PC combustion, 4 (17%) have fluidized bed combustion (FBC), 3 (12.5%) have supercritical boiler combustion, and 1 (4.17%) has ultra-supercritical boiler.

The capacities of young and old power plants larger than 200 MW in the 6-9 year range are at the same level for imported and domestic coal and range between 70-94% for 2022. Depending on the technology of the new plants (super and ultra-super boiler and fluidized bed combustion technology, etc.), the efficiency values ranging from 43-48% are more advanced and have higher capacity factors due to less breakdowns and capacity losses.

As regards capacity factor due to medium age, only Afşin Elbistan-B power plant has a CF<50%. It is observed that the imported and domestic coal resource use of all other plants operate with 70-80% capacity factor for 2022.

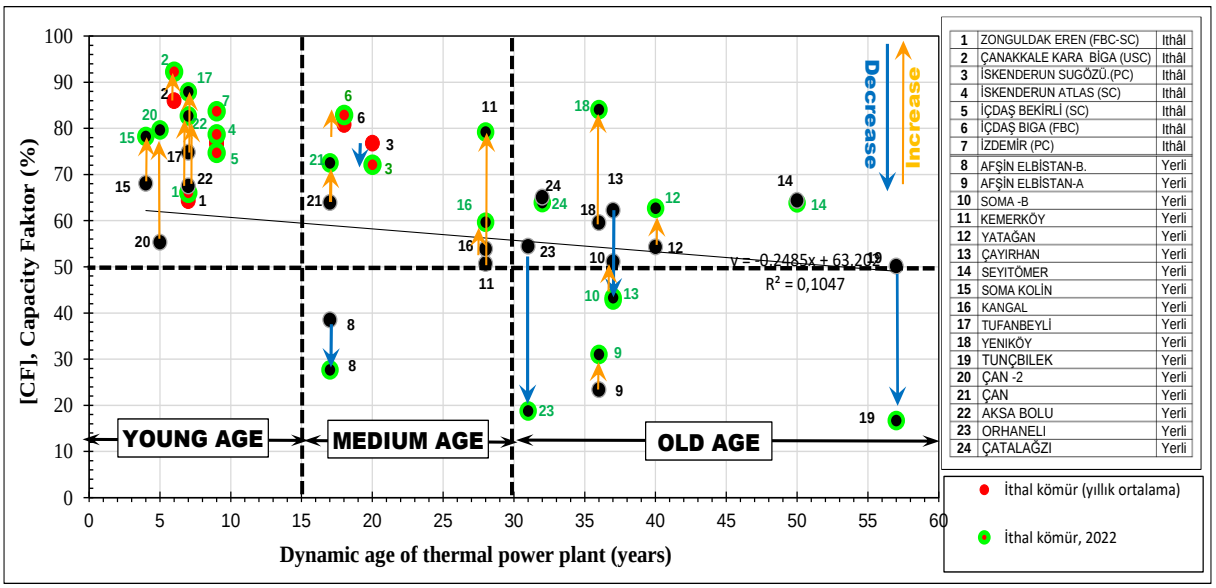

Figure 8. Dynamic age and capacity factors of domestic and imported coal-fired thermal power plants in Türkiye (> 200 MW)

It is noteworthy that capacity factor is low for domestic coal-fired power plants operated with old conventional combustion technologies without rehabilitation. Especially in middle-aged and older plants, CF=50-55% according to average annual production. It is considered that this situation may be primarily a result of old and aging combustion technologies, but also as a result of turning to alternative resources during periods of crisis threatening the security of energy supply or as a requirement of sudden fluctuations in fuel prices.

The increasing wear and tear on the power generating capacity of the power plant over time is greater than 30 years, and it is inevitable that the risk of failure increases with decreasing capacity at advanced ages. As the dynamic age increases, so does the need for maintenance, repair and optimization. Their operation without technological upgrades causes them to produce more pollutant gas emissions. For this reason, the necessity to operate less may also reduce the capacity factor.

It should also be kept in mind that deficiencies in planning and feasibility studies, as well as faulty operational policies, can also lead to low capacity factors (MMO, 2022; Yılmaz, 2023).

4.1. Technologies and Cost Analysis for The Energy Conversion Process of Thrace's Coals

Thrace region is dependent on foreign energy with a 76% share in terms of primary energy resources, so it is of great importance to transform the coal reserves of the region into power generation with an energy - economy - environment approach. Within the scope of this study, new generation electricity generation technologies that will transform the coal reserves of the region into energy in the short and long term are examined in terms of cost, applicability and efficiency. These technologies are high efficiency (40-45%) supercritical, ultra-supercritical combustion used in coal-fired power plants that have been installed in our country in recent years and gasification technologies.

Gasification is the process of converting coal into syngas through chemical reaction using oxygen and steam in a controlled manner under high temperature (>700 ^{0}C) and pressure (<10 MPa) (Aktan, 2020). Gasification technologies are divided into two categories: surface gasification, where the mined coal is processed and then gasified in chemical reactors which are located above ground, and in-situ gasification, which is produced through wells drilled from above ground without mining of coal. In-situ gasification stands out in the *"energy - economy – environment"* approach in terms of low cost and lower environmental impact comparing with surface gasification process. Research on underground gasification technology began in the early 20th century and intensive research was carried out in the former Soviet Union and the United States. Although the decline in natural gas prices at the end of the 20th century interrupted these studies, underground coal gasification remains important in Turkey and around the world today. Significant 20th century pilot-scale underground gasification projects around the world have been examined and relationship between the amount of gas produced and its calorific value depending on the thickness and depth of the seam are given in Figure 9. According to figure, it is seen that the thickness of the gasified seam varies between 1-18 m and the depth of the seam varies between 75-860 m. Edirne-Uzunköprü-Harmanlı coal seams are 1.10-1.70 m thick and 70-180 m deep and suitable for underground gasification according to the seam characteristics. An analytical prediction was tried between seam thickness and synthetic gas calorific value and the calorific value of synthetic gas to be produced after gasification for Harmanlı coals was estimated as 14.37 MJ/m^3. The evaluations and predictions made within the scope of this study are not definite values and it is recommended to install a pilot scale underground gasification plant in order to better understand the gasification process and efficiency as well as the properties of the syngas to be produced for the UGC ICC planned to be established in the region in the long term.

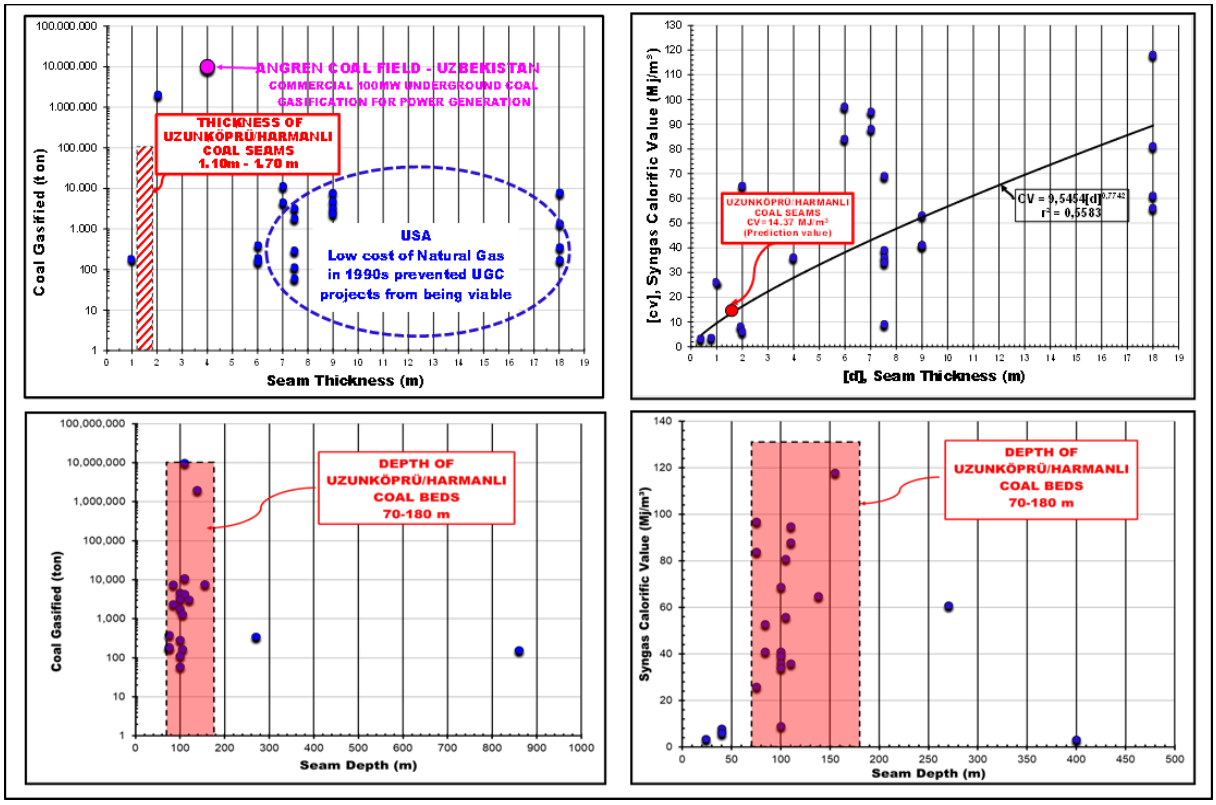

Figure 9. Data analysis of coal seam thickness and depth for the various field trials of UCG

Considering the fact that coal gasification studies for energy generation in our country are still in their infancy, and the length of the installation and testing phases of the on-site pilot-scale facilities that need to be carried out before the UCG-IGCC to be established in the Thrace region, the use of the region's coals for energy generation in a new generation thermal power plant in the short term stands out.

The rough performance and cost calculations for a coal-fired thermal power plant with an

installed capacity of 400 MW to be fed by the mechanized underground coal mine operating in Uzunköprü, Edirne are given in Table 1 and Figure 10.

Table 1. Thermal Power plant design performance parameters for Edirne-Harmanlı Coals.

Parameters	**Thermal Power Plants**			**Gasification**
	PCC	**SCPC**	**USC**	**UCG-ICC(*)**
• Plant capacity (MW)	400	400	400	400
• Plant efficiency (%)	35	42	45	50
• Capacity factor (%)	60	60	60	80
• Lower Heat Value of coal (kcal/kg)	4500	4500	4500	4500
• Coal haulage losses (%)	5	5	5	-
• Coal requirement (kg/MWh)	573	478	446	-
• Coal requirement (tons/400 MWh)	229	191	178	-
• Coal requirement (tons/year)	1 205 376	1 004 480	937 515	2 565 640

PC=Pulverized Coal, SC=Supercritical, USC= Ultra-Supercritical, UCG-ICC=Underground Coal Gasification Integrated Combined Cycle
(*) Adapted from Budak,2014.

According to evaluations, the capital costs for supercritical thermal power plant is calculated as 528-640 million $, while the cost for UGC ICC power plant is 576-700 million $. When electrical energy production costs are analyzed, the cost of 50 USD/MWh for SC and USC decreases to 47 USD/MWh for UCG-ICC technology. In terms of CO_2 emissions, an UGC IGCC power plant with carbon capture and storage technology stands out regarding environmental impact with a value of 100 kg CO_2/MWh compared to a natural gas power plant producing 400 kg CO_2/MWh. The annual coal requirement (0.93-1.2 million tons) of a thermal power plant with an installed capacity of 400 MW, which will operate with an annual capacity factor of 60 percent, can be easily met by an underground coal mine with a mechanized production method, and when UCG-ICC technology is preferred, it will be possible to gasify approximately 2.5 million tons of coal on site per year. Considering that the coal reserves in the region are 140 million tons, it will be able to feed the coal-fired power plant to be established until the end of its economic life.

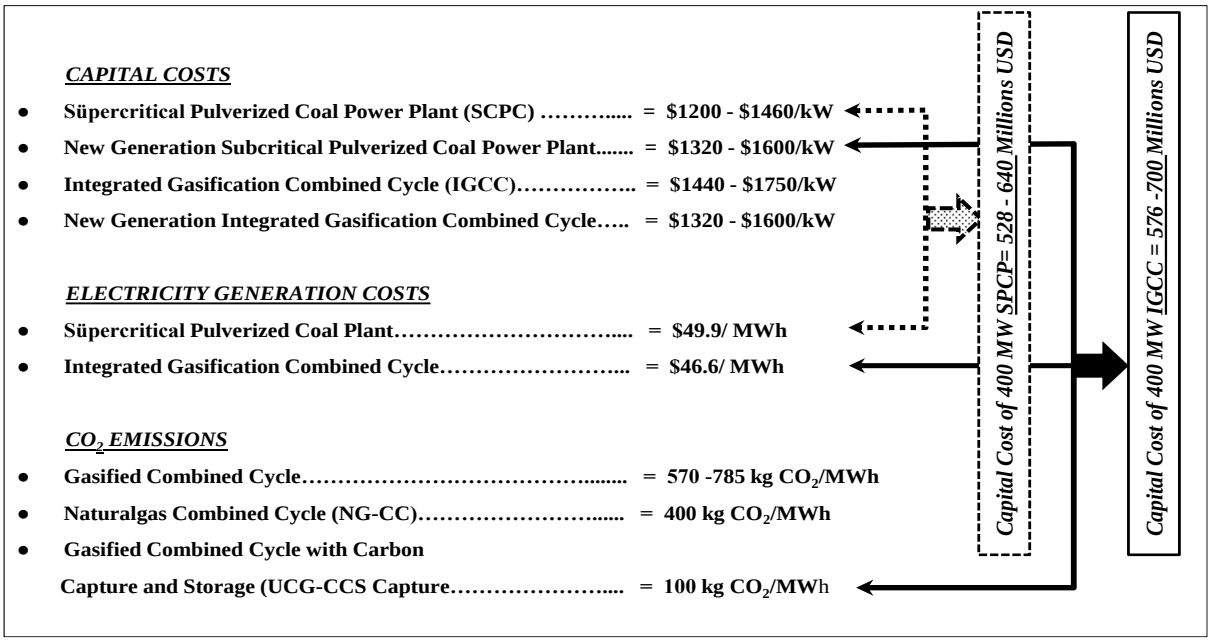

Figure 10. Cost and CO_2 emission values of thermal power plants and coal fired – gasified power plants (adapted from Takyi et al.2023).

5. Conclusions and Recommendations

Within the scope of this study, the main conclusions that can be reached from the numerical analysis and evaluations made during the process from coal production to clean energy source of the coal resources of the Thrace Region are listed below:

- The energy supply security of the Thrace region, 78% of which is based on imported natural gas, should be ensured by prioritizing the use of domestic resources. Energy policies based on imported resources in natural gas and hard coal, whose imports continue to increase, should be rapidly reduced. *In the short term*, the share of domestic coal-based energy in Thrace should be increased by at least 22-25%, as is the case with the share of wind-based energy, and resource diversity in the region should be prioritized. In this way, the 78% share of imported natural gas in the region's energy will be reduced to 25%.
- The rationalization achieved by the transition to full mechanization in the coal-based industry in the Thrace Region in 2019-2020 brought about a significant transformation in underground coal mines. This process has led to more effective and efficient production compared to traditional methods, while at the same time increasing occupational safety standards. With the adoption of mechanization, the actual production capacity of the mines has increased and a more sustainable production model has been established. Thanks to this rationalization, underground coal mines in the Thrace Region have become more competitive and contributed positively to the economic growth of the region.
- In the sustainability of Thrace's energy with zero emission new generation environmentally friendly thermal power plants; "mechanization in production" is necessary and important for coal production rate and continuity. Thermal power plant planning and design should not be made without mechanization in coal production.
- The underground mechanized mining method will prevent environmental pollution (soil and water pollution as well as topographical and visual pollution). Moreover, the ash problem (ash heaps on surface) of thermal power plant to be ınstalled will be prevented; since the ash will be transported to mine areas by hydraulic method after coal mined. This backfill method will also prevent surface collapses that may occur due to underground production, and there will be no need to select a separate backfill material.
- The Oligocene aged sub-bituminous coals of Edirne-Uzunköprü-Harmanlı have coal quality characteristics that can compete with imported coals. They need to be registered in this respect.

In briefly; based on the understanding of *"energy - economy - ecology"* in the sustainability of coal and energy production activities; in the short term, the Thrace region can convert its own reserves of 3.27 billion tons of sub-bituminous coal into energy with thermal power plant capacity options of 400-2000 MW without creating energy - environment conflict. *In the short term*, in this conversion process, a thermal power plant type with an efficiency ranging between 42% and 46% and especially with a "supercritical or ultra-supercritical fluidized bed (800-900ºC) can be preferred. If necessary, CO_2 emissions can also be prevented with carbon capture and storage (CCS) technologies, as well as units to remove SO_2 and NO_x emissions in flue gases (De-SO_2 and De-NO_x) (Tokgöz, 2006 and 2010). *In the long term*, the energy needs of Thrace can be met with a new generation underground gasification plant for coal equipped with new generation IGCC+CCS technologies. For this, the availability of sandstones in the Thrace Region as CO_2 emission storage (CCS) areas is an important issue that needs to be investigated urgently.

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ECO-FRIENDLY WASTEWATER TREATMENT TECHNIQUES IN CONSTRUCTED WETLANDS THAT PROMOTE ENERGY CONSERVATION

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ABSTRACT

Wastewater treatment plays a vital role in safeguarding both the environment and public health. However, traditional wastewater treatment methods typically demand substantial energy resources, contributing to environmental challenges and escalating costs. In response to this, constructed wetlands have emerged as an innovative and sustainable alternative for wastewater treatment. Unlike conventional methods, constructed wetlands operate as eco-friendly, energy-efficient systems that offer promising solutions to the challenges posed by energy-intensive treatment processes.

Constructed wetlands utilize natural processes and various plant and microbial interactions to treat wastewater effectively. The plants in these wetlands assist in absorbing nutrients and filtering pollutants, while the microorganisms break down organic matter. By harnessing these natural mechanisms, constructed wetlands significantly reduce the need for energy-intensive treatments, making them environmentally friendly and cost-effective.

This report delves into the application of energy-efficient technologies within constructed wetlands, exploring their intricate processes and mechanisms. These technologies leverage the power of biological and ecological interactions to efficiently treat wastewater. By optimizing the synergistic relationships between plants, microorganisms, and aquatic life, constructed wetlands can achieve high levels of treatment without the excessive energy consumption associated with traditional methods.

Furthermore, this report examines the future prospects of energy-efficient technologies in constructed wetlands. As advancements in ecological engineering and wastewater treatment continue to evolve, there is a growing potential for enhancing the efficiency and scalability of constructed wetland systems. Research and innovation in this field are paving the way for the development of novel technologies and approaches, ensuring that constructed wetlands remain at the forefront of sustainable wastewater treatment solutions.

Keywords: Wastewater, Constructed wetland, Eco-friendly technique.

Introduction:

Pharmaceutical compounds in wastewater have become a pressing environmental concern due to their potential ecological and health impacts. Constructed wetlands offer an innovative and nature-based solution for mitigating pharmaceutical contamination. This review aims to assess the performance and limitations of constructed wetlands in pharmaceutical compound removal.

Constructed wetlands employ various removal mechanisms for pharmaceutical compounds, including adsorption, microbial degradation, and plant uptake. These mechanisms are influenced by factors such as wetland design, hydraulic loading rate, and plant species.

Constructed wetlands offer a natural-based and environmentally benign approach of wastewater treatment in industrialized and developing Nations. Because water released from healthcare facilities has been proven to be hazardous, managing pharmaceutical and hospital wastewater is a difficult challenge for health and

environmental concern authorities worldwide (M. Zamparas et al., 2019). Constructed Wetlands have advantage over other treatment processes receivable to low cost, low energy consumption, and operational simplicity (Cabred et al., 2019). Constructed wetlands have been used successfully for both primary and secondary wastewater treatment. The treatment method is based on the biological, physical, and chemical synergies of plants and microbes for their substrate, which results in the removal of nutrients, organic, inorganic, and poisonous substances from the environment. Environmental pharmaceutical waste is a developing issue of concern on a global scale. Pharmaceutical waste is any trash that contains pharmaceuticals that are no longer needed, damaged, unused, or expired. The use of agricultural pesticides results in increased crop yields, but their effects are less than desirable when they leave agricultural ecosystems, especially by entering waterways (Maucieri, C., 2014). Recently, it has been shown in several studies that agricultural ditches with wetland vegetation may be useful traps for commonly used pesticides (Moore et al., 2001a). Constructed wetlands (CWs) have emerged as a sustainable and cost-effective solution for treating wastewater contaminated with agricultural and pharmaceutical pollutants. This review provides an overview of the application of CWs in the removal of these contaminants from wastewater.

Agricultural activities, such as crop cultivation and animal husbandry, often contribute to the release of various pollutants; include pesticides, fertilizers, and animal waste, into water bodies. Similarly, pharmaceuticals and personal care products (PPCPs) are frequently detected in wastewater due to their widespread use. These contaminants pose significant risks to aquatic ecosystems and human health, necessitating the development of effective treatment strategies.

CWs are engineered systems that mimic natural wetlands and utilize various physical, chemical, and biological processes to remove contaminants from wastewater. The design and operation of CWs can be tailored to target specific pollutants, including agricultural and pharmaceutical compounds. Key mechanisms involved in contaminant removal within CWs include sedimentation, filtration, adsorption, microbial degradation, and plant uptake.

Several studies have demonstrated the effectiveness of CWs in removing agricultural and pharmaceutical contaminants. The presence of vegetation, particularly emergent plants, enhances contaminant removal by providing a suitable habitat for diverse microbial communities that can degrade or transform pollutants. Additionally, the rhizosphere of wetland plants plays a crucial role in the uptake and transformation of contaminants, further improving treatment efficiency.

Various factors influence the performance of CWs for removing agricultural and pharmaceutical contaminants, including hydraulic loading rates, residence times, vegetation types, and nutrient availability. Optimization of these factors can maximize pollutant removal efficiency and ensure the long-term sustainability of CW systems.

Moreover, CWs offer additional environmental benefits such as habitat creation, carbon sequestration, and aesthetic value. However, challenges remain in terms of monitoring and managing potential risks associated with the release of treated effluent, including the potential for the development of antibiotic resistance in wetland microbial communities.

Materials:

To understand the nature, removal mechanisms, and removal efficiency of constructed wetlands, the following material and methods were employed in this study:

1. Literature Search: A comprehensive search was conducted to identify relevant research and review articles related to constructed wetlands and their role in pollutant removal. Online databases, such as PubMed, Google Scholar, and Science Direct, were utilized for this purpose. Key search terms included "constructed wetlands," "pollutant removal," "nature," "mechanisms," and "efficiency."
2. Article Selection: The identified articles were screened based on their relevance to the study objectives. Only articles published in peer-reviewed journals and written in English were included. The selection process involved assessing titles, abstracts, and full texts to ensure they provided insights into the nature, removal mechanisms, and removal efficiency of constructed wetlands (Alsubih, Majed, et al., 2022).
3. Data Extraction: Data related to the nature of constructed wetlands (e.g., design, vegetation, substrate), removal mechanisms (e.g., physical, chemical, biological processes), and removal efficiency for various

pollutants (e.g., nutrients, heavy metals, organic contaminants) were extracted from the selected articles. The information was recorded systematically to facilitate analysis and comparison (Khan *et al.*, 2023).

4. Data Analysis: The extracted data were analyzed to identify common trends, patterns, and variations in the nature, removal mechanisms, and removal efficiency of constructed wetlands (Alsubih, Majed, et al., 2022). This involved summarizing the key findings from each article, comparing different wetland types and designs, and evaluating the effectiveness of various removal mechanisms.
5. Synthesis and Interpretation: The analyzed data were synthesized to develop a comprehensive understanding of the nature, removal mechanisms, and removal efficiency of constructed wetlands. The findings from different studies were integrated to provide a holistic view of the subject matter. Interpretations were made based on the collective evidence and insights gained from the reviewed literature.
6. Limitations: The limitations of the reviewed articles, such as sample size, study duration, and geographical bias, were considered during the interpretation of the results. This ensured a balanced assessment of the literature and highlighted areas that require further research or clarification.

By employing these material and methods, this study aimed to provide a synthesized overview of the current knowledge regarding the nature, removal mechanisms, and removal efficiency of constructed wetlands, based on the findings from existing research and review articles in the field.

Constructed wetland techniques: Through a variety of physical, biological, and chemical processes, wetland systems can change and/or eliminate different contaminants (organics, nutrients, trace elements, etc.), improving the quality of the water. The abundance of ecological and economic advantages associated with wetlands sparked interest in taking advantage of their innate ability to purify water for a variety of purposes, most notably wastewater treatment. The purifying properties of natural wetlands are used by artificial wetland ecosystems, which have long been utilised to dispose of and treat secondary and tertiary wastewater effluents (Stefanakis, A., Akratos 2014). Point-source wastewater treatment is one of the initial applications of CWs. As a sustainable treatment procedure, this technology is recognised today. The numerous industrial applications of wetland technology demonstrate its great treatment capacity, as demonstrated by recent advancements in this sector (Masi, F., 2009). The primary problems with the prevalent mechanical treatment methods that rely heavily on energy are the high costs associated with both development and operation. Because of their unsightly, industrial look, conventional treatment plants are typically located far from residential areas. Large mechanical components (aeration units, pumps, etc.) and a lot of non-renewable resources (steel and concrete, for example) are used in their equipment.

Result and Discussion:

Based on various research papers, the removal of pharmaceutical and agricultural waste from wastewater using constructed wetlands has shown promising results. Here are some key findings and discussions from the literature:

1. Pharmaceutical Waste Removal:

- Several studies have demonstrated that constructed wetlands can effectively remove pharmaceutical compounds from wastewater. Removal efficiencies vary depending on the specific compounds and wetland design (Khan *et al.*, 2023).
- The processes involved in pharmaceutical waste removal include adsorption onto wetland plants and substrate, microbial degradation, and plant uptake (Li, Yifei, et al., 2014).
- Pharmaceuticals such as antibiotics, hormones, and nonsteroidal anti-inflammatory drugs (NSAIDs) have been successfully removed by constructed wetlands, with removal efficiencies ranging from 40% to over 90 %(Alsubih, Majed, et al., 2022).
- Factors influencing removal efficiency include the presence of suitable wetland vegetation, longer hydraulic retention times, and the presence of oxygenated zones for microbial activity (Ilyas, Huma et al., 2020).

2. Agricultural Waste Removal:

- Constructed wetlands have demonstrated the ability to remove various agricultural pollutants, including nutrients, pesticides, and herbicides (Díaz, Francisco Jet al., 2012).
- Nutrient removal, particularly nitrogen and phosphorus, is one of the primary benefits of constructed wetlands for agricultural wastewater treatment. Wetland plants and microbial processes contribute to the efficient removal of these nutrients (Saeed, Tanveer, et al., 2018).
- Pesticide and herbicide removal in constructed wetlands is influenced by factors such as chemical properties, wetland design, and the presence of specific wetland plant species. Removal efficiencies can vary widely, ranging from moderate to high levels (Moore, M. T., et al., 2001).
- The presence of wetland plants plays a crucial role in the removal of agricultural waste by promoting filtration, adsorption, and plant uptake processes (Maucieri, Carmelo, et al., 2014).

3. Synergistic Effects:

- The combined removal of pharmaceutical and agricultural waste in constructed wetlands can exhibit synergistic effects. For instance, certain wetland plant species can facilitate the removal of both types of pollutants simultaneously.
- Studies have reported enhanced removal of pharmaceuticals when wetlands are also treating agricultural runoff. This can be attributed to increased microbial activity, greater organic matter availability, and the presence of additional adsorption sites.

4. Factors Affecting Removal Efficiency:

- The design and operational parameters of constructed wetlands significantly impact the removal efficiency of pharmaceutical and agricultural waste. These include hydraulic retention time, vegetation type, substrate composition, flow patterns, and influent pollutant concentrations.
- Wetland vegetation selection is critical for successful removal. Certain plant species have shown higher affinity for specific pollutants, leading to improved removal efficiencies.
- The presence of oxygen in the wetland system is crucial for aerobic degradation processes, and anoxic zones promote denitrification and reduction of certain pollutants.

5. Limitations and Challenges:

- The effectiveness of constructed wetlands for pharmaceutical and agricultural waste removal can be influenced by the complex nature of the pollutants, their persistence, and their varying concentrations in wastewater.
- Long-term performance and the potential for accumulation of certain pollutants in wetland systems require further investigation.
- It is essential to address the potential risks associated with the release of transformed or metabolized by-products during the removal processes.

Conclusion:

Constructed wetland offer an effective and sustainable solution for the treatment of wastewater that can benefit both the environment and human health. They require minimal energy and maintenance are cost-effective and provide habitat for wild life. The design and operation of the wetland will depend on the specific application and the characteristics of the wastewater being treated, but overall, constructed wetlands are an environmentally friendly and cost-effective method of wastewater treatment. In conclusion, constructed wetlands have shown promise for the removal of pharmaceutical and agricultural waste from wastewater. However, further research is needed to optimize wetland design, plant selection, and operational parameters to enhance removal efficiency and address the challenges associated with the treatment of these specific waste streams.

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SYNTHESIS and CHARACTERIZATION OF A P(VCL-co-AA) COPOLYMER AS THERMOTROPIC POLYMER

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ABSTRACT

Poly(vinyl caprolactam) is a well-known material for its thermotropic properties. It is also known that it is possible to adjust phase transition temperature to higher degrees of temperature by incorporating it with hydrophilic monomers. Acrylic acid (AA) is one of the monomers that has not been used for this purpose. Here in this work, it has been produced and tested for the phase transformation characteristics and thermotropic properties. H-NMR, GPC, DSC, TGA, and FTIR Spectroscopy analysis were used for characterization. POM was also operated to show the surface morphology difference between the synthesized material and precursor.

Keywords: thermotropic material, thermal energy storage material, vinyl caprolactam.

Introduction

Polymers that vary depending on environmental changes (pH, temperature, pressure, etc.) are called smart or stimuli-responsive polymers. The fact that smart polymers alter depending on environmental conditions has made them attractive for use in construction and textile fields (Kieviet, Schön, and Vancso 2014; Roy and Gupta 2003).

Thermo-responsive polymers are smart polymers that change physically or chemically depending on temperature changes as an environmental factor. Depending on the alteration in temperature of solutions of thermo-responsive polymers, a phase transition occurs as an observationally detectable change in the switching temperature called the critical solution temperature (LCST). These smart materials become from hydrophilic to hydrophobic structures depending on the temperature. The alteration occurs when the temperature value rises above the LCST; that is, it changes from a transparent appearance to an opaque one. (Qiu and Park 2001).

Poly (N-isopropyl acrylamide) (PNIPAM) is a thermo-responsive polymer that is very important in this field, and its LCST is known to be 32°C. Poly(vinyl caprolactam) (PVCL) is another polymer that attracts attention among heat-sensitive polymers due to its LCST being 34°C. Although it is close to the LCST of PNIPAM, it exhibits higher biocompatibility and is, therefore, more evaluated in life science. (Cortez-Lemus and Licea-Claverie 2016; Rao, Rao, and Ha 2016).

PVCL is a polymer with a thermo-responsive LCST of 34°C, and many hydrophilic and hydrophobic monomers have been used to produce new copolymers that exhibit phase change at different temperatures while maintaining the thermosensitive properties of this polymer (Cortez-Lemus and Licea-Claverie 2016).

In this study, vinyl caprolactam (VCL) and acrylic acid (AA) monomers were synthesized together for the first time to produce a new temperature-responsive copolymer. Poly (vinyl-co-acrylic acid) (P(VCL-co-AA) polymerized by the free radical polymerization method was chemically characterized by Fourier-transform (FT-IR) spectroscopy. UV-visible spectroscopy and optical microscopy were used to characterize it physically. Further, turbidity analysis was made to evaluate the LCST behavior of this copolymer.

Materials and Methods

Materials

Vinyl caprolactam (VCL), acrylic acid (AA), and 2,2′-azobis (2-methylpropionitrile) (AIBN) were all purchased from Sigma-Aldrich. Toluene and diethyl ether (Merck) were used as solvent.

Synthesis of P(VCL-co-AA)

The synthesis of P(VCL-co-AA) was carried out by free radical polymerization in the presence of toluene. (González and Frey 2017). The reaction was performed under N_2 gas in a three-necked, round-bottom flask equipped with a reflux condenser. First of all, VCL and AA (0.1%) monomers, and AIBN to be used as initiator were dissolved separately in toluene. The reaction medium was formed by combining monomers dissolved in toluene and AIBN dissolved in toluene, and this medium was left to react at 70°C for 5 hours. The environment was brought to room temperature to terminate the reaction, and diethyl ether was added to the environment to precipitate the copolymer. The copolymer was isolated by vacuum filtration and dried under vacuum at 40°C overnight. The scheme of the synthesis is drawn as shown in Figure 1.

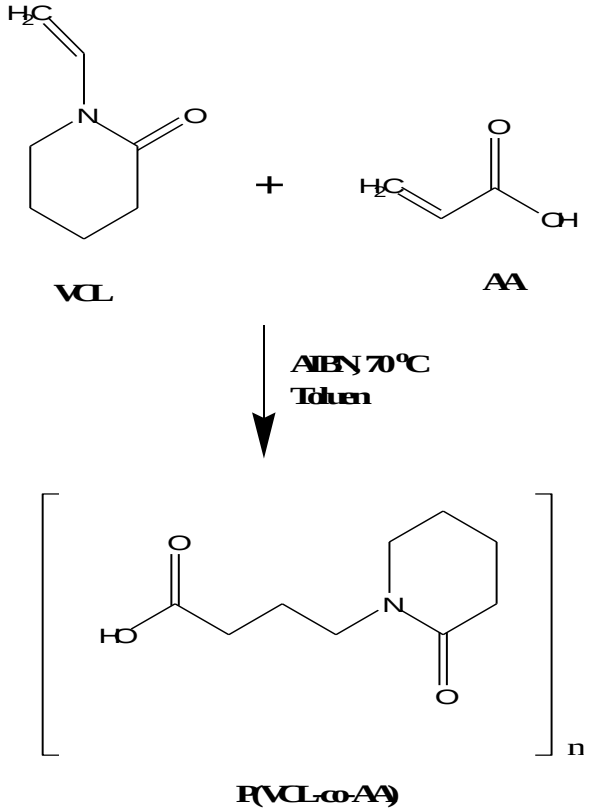

Figure 1. The scheme of synthesis P(VCL-co-AA)

FT-IR Spectroscopy

FT-IR spectroscopy (instrument model Jasco 430) was used to determine the chemical characterization of P(VCL-co-AA). The copolymer compound was scanned by FT-IR at a wavenumber range of 400-4000 cm^{-1}.

UV-Visible Spectroscopy

One of the important evaluations for LCST analysis is the determination of the absorbance peak of the material at room temperature. A solution of P(VCL-co-AA) copolymer (1% (v/v)) was prepared using distilled water, and the absorbance peak of the copolymer solution was measured by UV-visible spectroscopy in the wavelength range of 200-800 nm.

Optical Microscopy Analysis

The optical appearances of vinyl caprolactam and P(VCL-co-AA) were observed using Leica Polarized Optical Microscopy DM EP (Germany, 2010).

LCST by Turbidity Investigation

LCST of P(VCL-co-AA) was evaluated by turbidity method with the help of a Spectrofluorometer (Jasco FP-8300) device (Abdelaty 2022). First, the maximum emission and excitation peaks of P(VCL-co-AA) solution (1% (v/v)) were measured at 277.5 nm and 302.5 nm, respectively. After that, to draw a graph of intensity versus temperature, the copolymer solution was heated at 2 °C /min and scanned in the 200-800 nm wavelength range.

Findings and Discussion

FTIR spectroscopy is a frequently preferred method to determine the chemical structure of polymers. (Riaz and Ashraf 2014). The reasons why the structure of polymers cannot be determined by NMR spectroscopy include solubility, unexplained peaks, and the polymer to be analyzed is highly cross-linked or thermoset polymer. (Cheng and English 2002). In this study, the FTIR Spectroscopy method was used to prove whether the copolymer was synthesized successfully. Therefore, both monomers (VCL and AA) and the produced copolymer were presented identically (Figure 2). In the FTIR analysis, it was investigated whether the characteristic peaks of the monomers used in copolymer synthesis were present in the copolymer that was produced. Considering the monomer ratios in copolymer synthesis, it can be seen that VCL is used at a high rate. In this case, since VCL is the copolymer's main monomer, the VCL's peaks are more dominant than those from acrylic acid. As a result, characteristic peaks of both monomers were observed in the copolymer. Some with minor changes better proved polymerization. The other point is that it is examined whether the double bond peaks of vinyl monomers generally observed in the range of 1600-1650 cm^{-1} is there or not (Sun and Wu 2011).

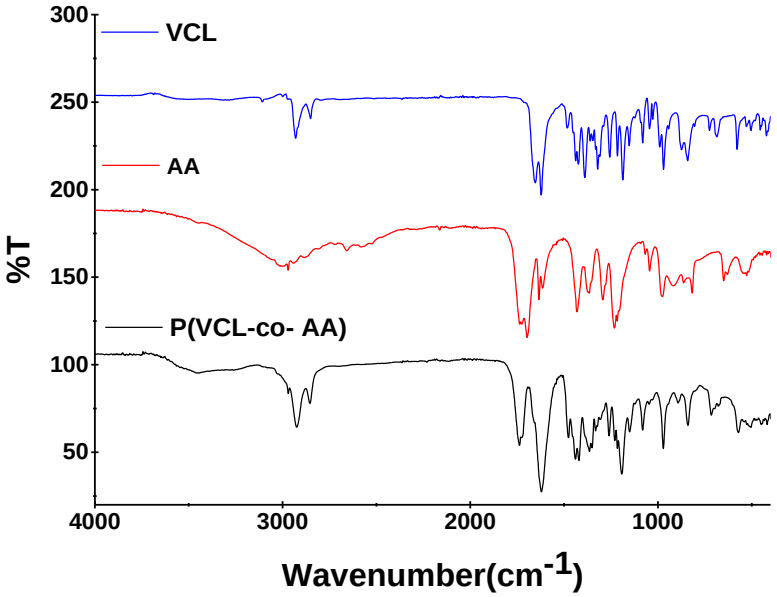

Figure 2. The FT-IR spectra of P(VCL-co-AA)

In polymer solutions, UV-visible spectroscopy analysis is used to reveal whether polymers have functional groups (double bonds, nitrates, amines, chromophores, etc.) (Mujahid and Dickert 2012). UV-Visible spectrum of P(VCL-co-AA) was shown in Figure 3. It can be seen in Figure 3 that the P(VCL-co-AA) copolymer, which is transparent at room temperature, does not have any peaks belonging to a functional group in the visible region. The single peak shown in the figure at a very low wavelength in the UV region is due to other chemical groups not usually interpreted in UV-Visible studies.

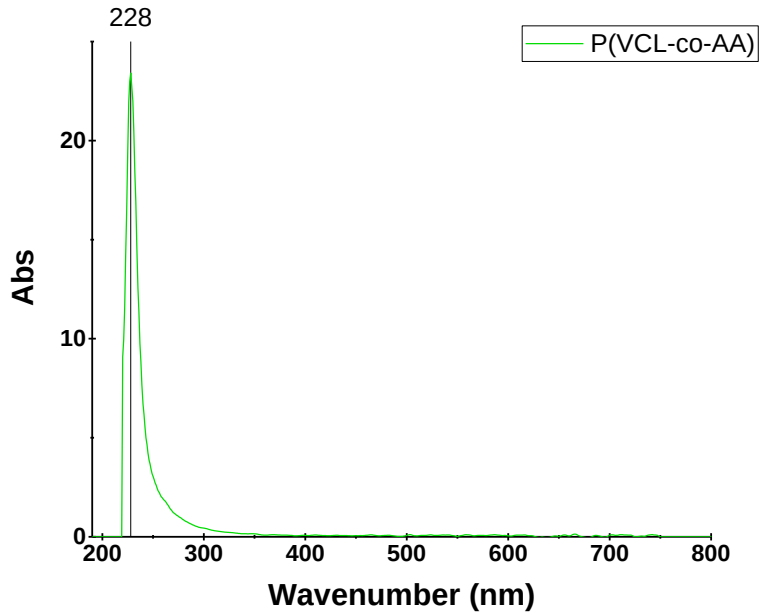

Figure 3. The UV-visible analysis of P(VCL-co-AA)

LCST of 1% P(VCL-co-AA) copolymer solution was analyzed by turbidity method. The curve shown in Figure 4 was drawn using the absorbance-dependent temperature change data of this analysis, which was defined as the turbidity curve. AA is a hydrophobic monomer and it is known that hydrophobic monomers reduce the switching temperature of thermos-responsive polymers (Xie, Li, and Chu 2007). The LCST of PVCL polymer is approximately 34 °C, and the LCST of the P(VCL-co-MA) copolymer solution synthesized for the first time in this study was measured as 24 °C. This value was lower than the LCST of PVCL, as expected. The ratio of monomers used in copolymer synthesis determines the operating temperature. This copolymer, with a monomer ratio of 0.1/99.9, was perfectly adapted to the building energy management application, which was evaluated as a potential application. Depending on the AA content in the copolymer, the changes are always in the same direction.

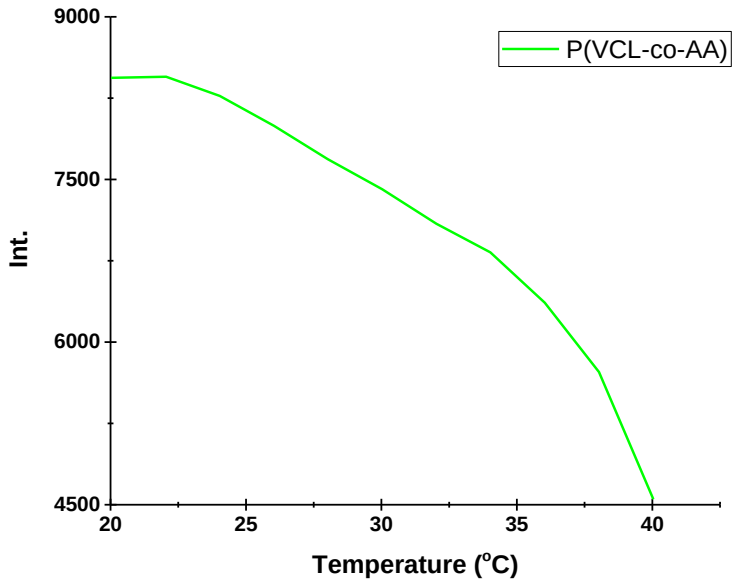

Figure 4. The turbidity analysis of P(VCL-co-AA)

Analyzing the physical appearance of polymers using optical microscopes with different illumination angles is an advanced form of image analysis (Sawyer, Grubb, and Meyers 2008). n this study, it was evaluated that PVCL polymer has an amorphous structure and is collectively more brittle than P(VCL-co-AA). Optical images of VCL and P(VCL-co-AA) are presented in Figure 5, and it can be clearly seen that the copolymer has a hard material form.

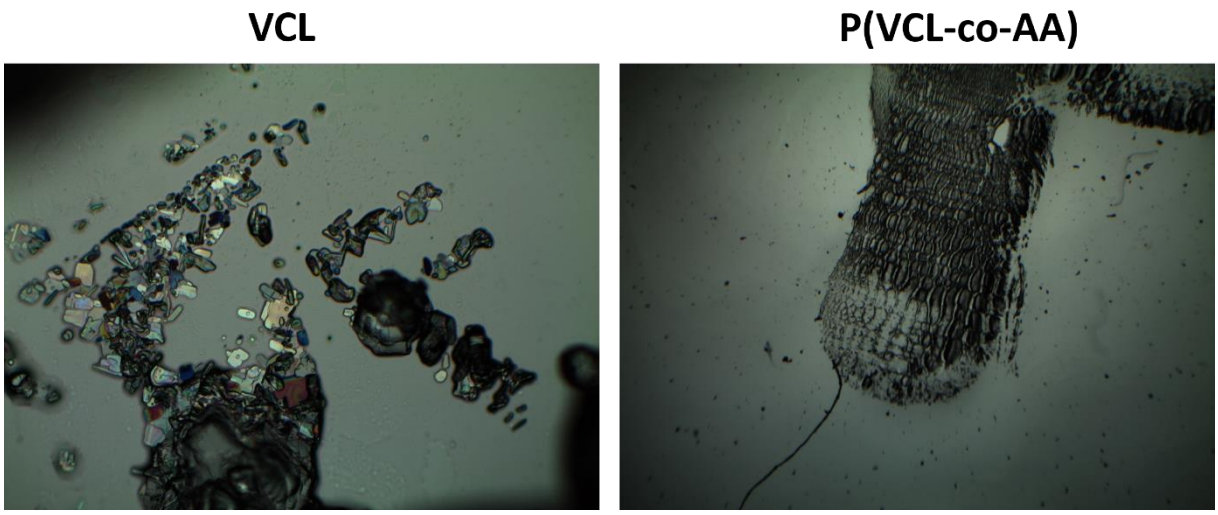

Figure 5. Optical microscope images of VCL and P(VCL-co-AA)

Conclusion and Recommendations

In this presented study, P(VCL-co-AA) copolymer was successfully polymerized and characterized for the first time as a new thermo-responsive polymer. It was revealed that the AA monomer used in the copolymer synthesis reduces the LCST of the polymer system. Thus, in this study, a new smart copolymer with a reversible transformation feature was produced, and it transforms from transparent to opaque during heating and from opaque to transparent during cooling to comply with the existing energy management systems.

While the physical properties of P(VCL-co-AA) copolymer were determined by UV-vis spectroscopy and turbidity analysis, its chemical structure was analyzed by FTIR spectroscopy. Polarized optical microscopy was used to monitor the physical appearance of PVCL and P(VCL-co-AA) copolymer. This new copolymer material exhibits unique properties and may be shown as a promising candidate as a thermo-responsive smart material for the effective management of energy used by buildings.

Thanks, and Information Note

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1,4-PHENYLENE DISTEARYLAMIDE AS A NOVEL PHASE CHANGE MATERIAL FOR THERMAL ENERGY STORAGE

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ABSTRACT

New generation phase change materials for thermal energy storage applications are a hot topic due to the low application potential of the present materials and the benefits produced by further functionality. Amine groups in these materials are especially important due to their donated metallic structure to impart energy-harvesting properties to their derivatives. For this reason, 1,4-phenylene distearylamide has been prepared as a potential material to exploit around its phase transition temperatures. In this study, 1,4-phenylene distearylamide has been identified with its thermal energy storage properties. DSC, TGA, and FTIR Spectroscopy analysis were used for characterization. POM was also operated to show the surface morphology difference between the synthesized material and precursor.

Keywords: phase change material, thermal energy storage material, fatty amide.

Introduction

Energy resources are continuous and reliable, and to meet increasing energy needs, it is necessary to derive and use renewable energy resources instead of existing energy resources. The production and dissemination of thermal energy storage (TES) systems is a vital energy strategy for effectively using thermal energy, one of the renewable energy sources (Kaplan et al. 2023). Materials that have been developed and continue to be developed to store thermal energy and use it when needed are called phase change materials (PCMs). For PCMs to be evaluated in TES systems, they must be adequate, functional, and suitable for long-term use. The absorption or release of heat is a reversible phase change phenomenon, and the use of PCMs in TES systems is based on this principle (Arndt et al. 1984; Zalba et al. 2003; Sharma and Sagara 2005; Li and Ding 2007c).

Many different materials, such as organic (Feldman et al. 1995b; Singh et al. 2021), inorganic compounds (Tyagi and Buddhi 2008), paraffins (Alkan 2006; Zhang and Fang 2006), and polymeric materials(Pielichowski and Flejtuch 2005; Li and Ding 2007c), are being investigated and improved as PCM. The advantages of fatty acids that make them suitable candidates for systems that provide passive heating with solar energy include being chemically stable for a long time, being non-toxic, and having a suitable melting temperature. Undoubtedly, besides the advantages of fatty acids, there are also a few disadvantages: corrosive effect, lousy odor, high sublimation rates, etc. It is necessary to overcome the impediments to benefit from the advantages of fatty acids. This has become possible by producing many fatty acid derivatives through esterification reactions (Feldman et al. 1995a; Rozanna et al. 2005; Li and Ding 2007a, b; Alkan et al. 2008, 2023; Canik and Alkan 2010).

In the presented study, a new PCM, 1,4-phenylene stearyl amide (PHDSA), was synthesized by reacting stearoyl chloride and 1,4 phenylene diamine. Stearoyl chloride is obtained by converting stearic acid, also known as a fatty acid. Stearic acid and its derivatives have been used as PCM in many studies before. Since phenylene is a self-crystallizing molecule, 1,4-phenylene diamine was used to obtain a hard-centered compound. PHDSA was synthesized for the first time in this study and was characterized as a new PCM in terms of physicochemical properties and thermal energy storage properties.

Materials and Methods

Materials

1,4-phenylene diamine and stearoyl chloride in the synthesis and toluene to be used as solvent were purchased from Sigma-Aldrich. Acetone and ethanol (Merck) were used to remove impurities.

Synthesis of PHDSA

PHDSA compound was synthesized in a 100 mL polytetrafluoroethylene double-neck valve vial permeated with nitrogen gas. First, 1,4-phenylene diamine (in a slightly more than stoichiometric amount) was dissolved in toluene at 100 °C, then stearoyl chloride (in a stoichiometric ratio) was added to the mixture and reacted for approximately 4 h. After the reaction was completed, PHDSA was washed with acetone followed by ethanol to remove impurities. (Gökşen Tosun et al. 2022). The scheme of synthesis was drawn as shown in Figure 1.

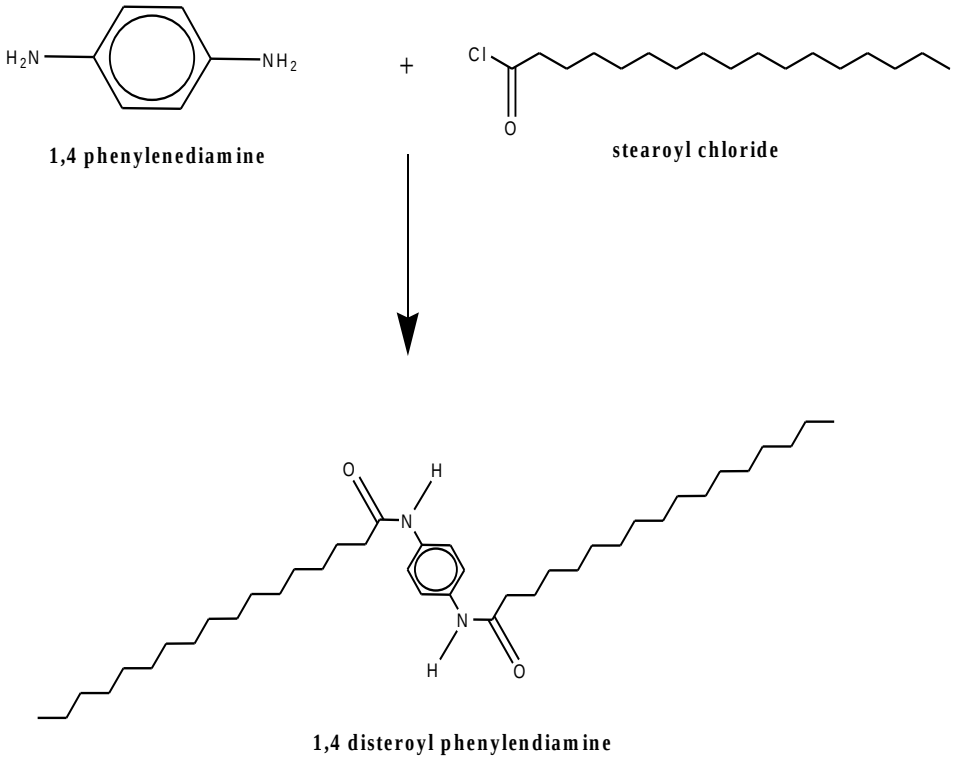

Figure 1. The scheme of synthesis PHDSA

FT-IR Spectroscopy

FT-IR spectroscopy was used to characterize PHDSA chemically. The PHDSA compound was scanned with FT-IR (instrument model Jasco 430) in the range of 400-4000 cm^{-1}.

DSC Analysis

Thermal properties of PHDSA, such as phase change points and enthalpy values occurring at phase change moments, were measured from DSC curves. DSC curves were performed using a DSC instrument (Netzsch DSC214 Polyma), and the instrument calibration was performed with an indium standard before use. After the temperature data was set to 5 °C min-1 under nitrogen gas (60 mL/min), the measurement intervals were set to 30 °C -110 °C (Pielichowski and Flejtuch 2003).

Polarized Optical Microscopy Analyses

Surface crystalline morphologies of stearoyl chloride and PHDSA were evaluated using Leica polarized optical microscopy DM EP (Germany, 2010).

Determination of thermal stability by thermal cycling test

Thermal stability analysis was performed to prove the long-term usability of PHDSA, which is intended to be used as an energy storage material. Storage characteristics were determined to prove consistency. The stability of PHDSA synthesized in this study was determined by heating it to 110 °C and then cooling it to 30 °C using BIDER-TC -25/H. Long-term use was achieved using a thermal cycling device, programming the PHDSA to be heated and cooled 1000 times (from 30 °C to 110 °C).

Results and Discussion

FT-IR Spectroscopy method has been used to identify some of the organic and inorganic materials' specific groups, and by the way materials, themselves. For this reason, the specific peak positions of expected groups are searched in the spectrum which were obtained by infrared light application and absorption/transition measurements several times. For a synthesized material, precursors are measured for comparison to the synthesis product which enables the characterization and possible changes in the material structure. Figure 2 in this work is a good example that clearly showed that the specific carbonyl group in the precursor stearoyl chloride shifted to 1738 cm^{-1} from 1784 cm^{-1}. 1,4-phenylene diamine does not have a carbonyl. Also, the persisting NH_2 groups coming from the 1,2-phenylene diamine turned to NH primer amines not so much characteristic in the produced PHDSA. When the other groups from the precursors, except for the ones in the fingerprint region, were searched, they were all found in the spectrum of the synthesized material. Fingerprint region is not considered in general.

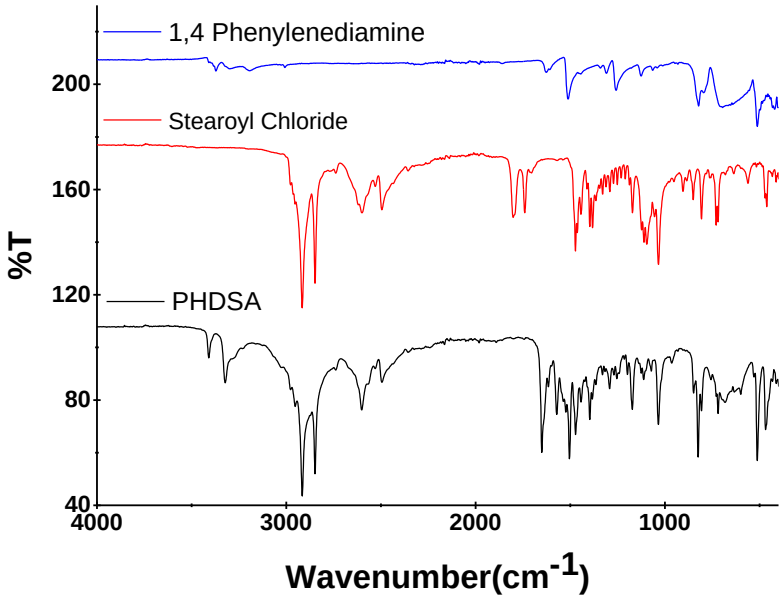

Figure 2. The FT-IR spectra of PHDSA

DSC is a technique that is used to determine not only the physical characteristics of the materials but also some application performances like in this study (Pielichowski and Flejtuch 2003). Figure 3 shows DSC curves during heating (in red color) and cooling (in blue color). The instrument is programmed stepwise and the peaks near the starting points are due to the material response to programming change. The curves include 2 physical changes; the former of which is due to solid-solid phase change as the latter one is due to solid-liquid in the heating period. In return, during the cooling period first peak is due to the liquid-solid transition as the second one is due to the solid-solid phase transition. Despite the big enthalpy change that occurs in solid-solid transitions, these materials should be thought as solid-liquid because the phase transition peaks are not well distributed. On the other hand, the enthalpy values are not much for good exploitation, and the materials can then be better used in temperature sensory applications or additives to thermal energy storage materials to modulate temperature in other materials like paraffin, fatty acids, and fatty alcohols (Rozanna et al. 2005).

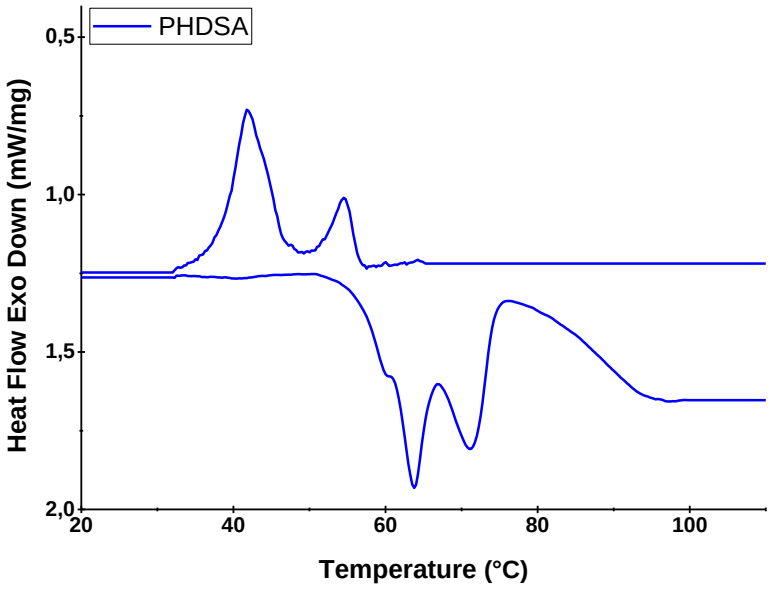

Figure 3. The DSC curve of PHDSA

DSC instrument can also be operated to determine temperature dependent specific heat capacity (Cp) which is primary indicator of sensible heat storage capacity (Alkan et al. 2023). Cp can be determined by programming the DSC instrument in a different way and therefore can be measured and shown only for heating as a single curve (Figure 4). Actually, the value is theoretically the same for the measured material if measured for cooling period. Cp goes to infinity during phase transformations. Cp data are listed in Table 1 for below and above the phase transition temperature. The table shows that the Cp values well before and after phase transitions were considerable, which means that the materials could be successfully exploited in sensible heat storage applications. Total enthalpy curves are another evidence of that the materials could be used as sensible heat storage materials.

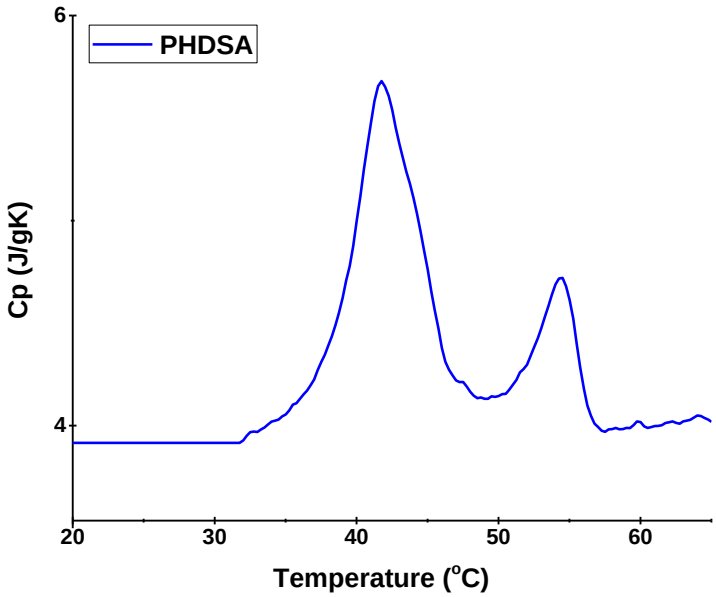

Figure 4. The Cp curve of PHDSA

Table 1. Cp value of PHDSA compound

Temperature °C	0	10	20	30	40	50	60	70	80	90	100
Cp(J/g*K)	3.92	3.92	3.92	3.92	5.00	4.14	4.02	4.15	4.79	5.16	4.34

To determine the total amount of stored heat energy, the total enthalpy graphs shown in Figure 5 were drawn using the data obtained from the DSC curves. The energy calculated by taking into account the sum of sensible and latent heat in a certain range determines the total heat energy storage ability of phase change materials.

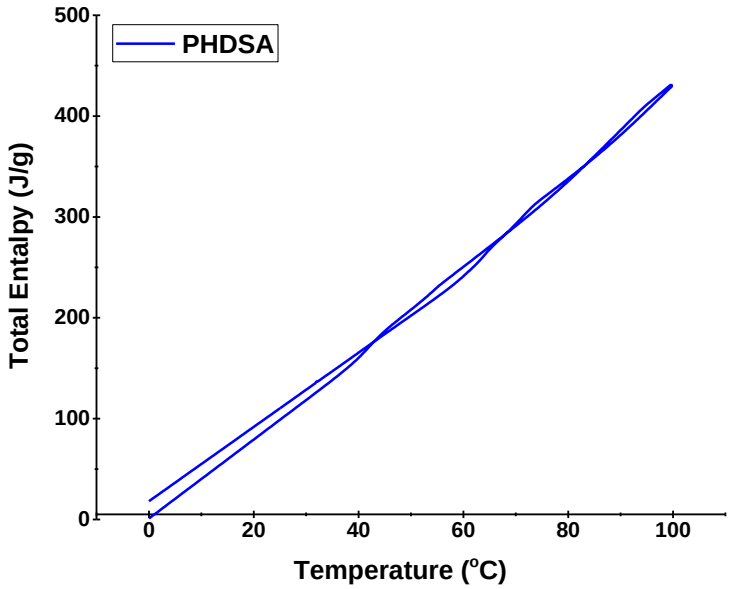

Figure 5. Total enthalpy value of PHDSA compound

Small detectable changes in surface micrographs can be evaluated by polarized optical microscopy. In this study, the solid structures of the produced PHDSA material and the stearoyl chloride were compared using a polarized optical microscope. As photographed in Figure 6, it was shown that the crystal surface morphology of PHDSA differs from stearoyl chloride with minor differences, crystalline size of the produced materials is much less than stearoyl chloride.

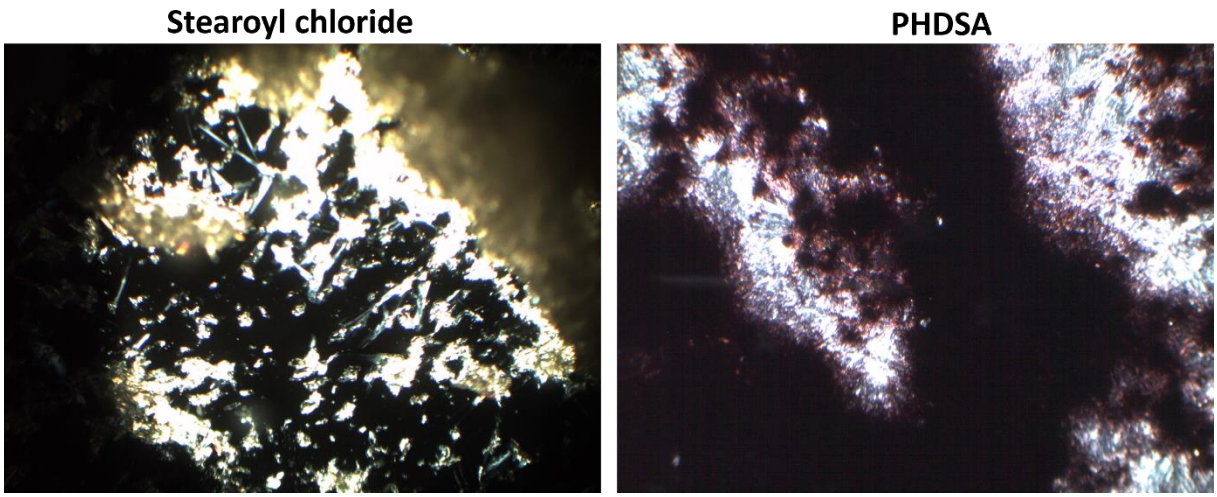

Figure 6. POM images of Stearoyl chloride and PHDSA

After PHDSA was heated and cooled 1000 times with a thermal cycling device, its long-term usability was measured with a DSC instrument. Thermal stability is one of the most important properties of TES material. After repeated 1000 times heated and cooled, melting and crystallization temperatures of PHDSA were measured as 38.6 °C and 78.0 °C, respectively.

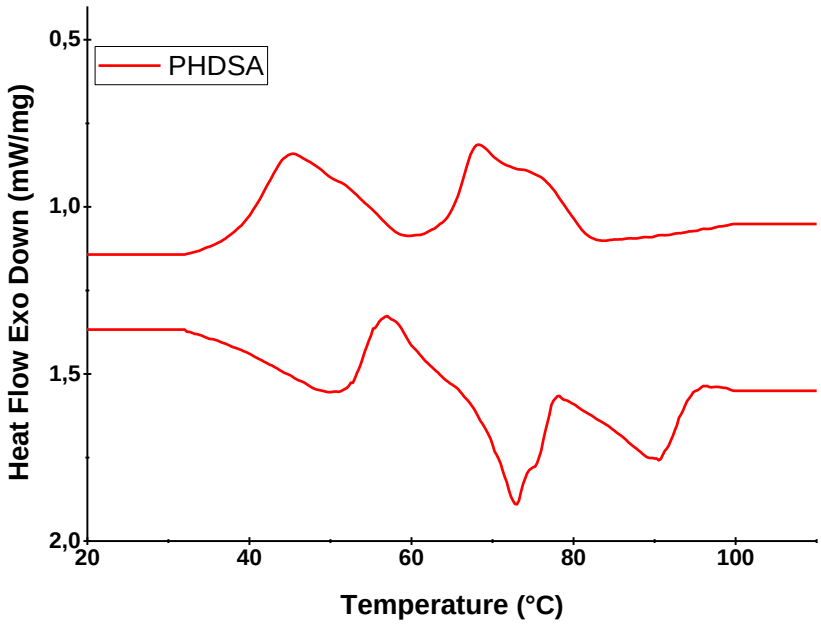

Figure 7. DSC curves of PHDSA after thermal cycling process

At the end of thermal cycling operations, it is clearly seen that the thermal property of the PHDSA material is consistent. The only value of the first transition temperature during heating is slightly high but at rest, the temperature and enthalpy of the values are always regular. The first measurements were sometimes slightly high and not dependable due to trace materials present in the system as impurity.

Table 2. TES characteristics of PHDSA in case of thermal cycling operations

Before thermal cycling	First phase transition temperature (Heating period) (°C)	Enthalpy (Heating period) (J/g)	First phase transition temperature (Cooling period) (°C)	Enthalpy (Cooling period) (J/g)
PHDSA	38.2	14.2	74.6	-22.4
After thermal cycling	**First phase transition temperature (Heating period) (°C)**	**Enthalpy (Heating period) (J/g)**	**First phase transition temperature (Cooling period) (°C)**	**Enthalpy (Cooling period) (J/g)**
PHDSA	38.6	14.1	78.0	-22.1

Conclusion and Recommendations

Derivatives of fatty acids are among the widely researched materials due to their potential for operating temperatures in the field of thermal energy storage. Acid groups at the ends of aliphatic chains in fatty acids can cause corrosion.

In this study, PHDSA was synthesized using stearoyl chloride and 1,4-phenyl diamine and characterized as a new PCM capable of being used in thermal energy storage. PHDSA is a fatty acid derivative and was successfully synthesized under reaction conditions. Evidence of the success of PHDSA synthesis and analysis of its chemical structure was revealed by FTIR spectroscopy. Physical characterization of PHDSA was performed by DSC and polarized optical microscopy. Characterization data of the fatty acid derivative PHDSA synthesized in this study revealed that it may be a new PCM candidate to be evaluated in thermal energy storage areas.

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EXAMINING THE MULTIPLE ELECTRIC VEHICLE PERFORMANCE OF BATTERY BUFFERED DC FAST CHARGER

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ABSTRACT

Nowadays, along with the widespread adoption of electric vehicles (EVs), there has been an acceleration in research on charging station solutions. Among these solutions, direct current (DC) fast-charging stations, with the advantage of short charging times, enable users to embrace EVs more rapidly and allow them to travel without concerns about range or charging. However, due to the high installed power and instantaneous high-power demands of DC fast charging stations, they may negatively impact the local power grid. These charging stations can lead to the rapid reaching of power limits in regions where the local grid infrastructure is old and weak, thereby causing power quality issues and grid fluctuations that could negatively impact the operation of other loads. To address such issues, studies and developments are being conducted on commercial and academic levels for DC fast charging stations equipped with battery storage units. These products offer voltage/frequency support to the grid while limiting the power drawn from the grid. They provide a significant portion of the high charging power required by EVs, primarily through buffer batteries. In addition to aforementioned advantages, the related system allows to integrate the renewable energy sources into this system with the common DC bus. In this study, a performance analysis of a battery-buffered DC fast charging station with two electric vehicles has been conducted. For this purpose, a charging station has been modelled in MATLAB/Simulink, incorporating a 30 kW bidirectional grid rectifier, a 150 kW unidirectional DC-DC converter, and a buffer battery. The performance of the charging system has been examined under conditions of synchronously and asynchronously charging two EVs, providing voltage/frequency support to the grid, and buffering the battery from the grid. The results of the battery-buffered DC fast charging station, tested under all possible power flow scenarios, confirm the system's efficiency and feasibility.

Keywords: DC fast charger, battery, buffer, electric vehicle.

Introduction

Electric vehicles (EVs) are becoming increasingly prevalent in line with carbon emission targets, propelled by advancements in the battery industry and the growing global demand for clean energy. According to (IEA, 2023), EV sales worldwide experienced a record-breaking 55% growth last year, surpassing 10 million units. The share of EVs in total vehicle sales has reached 14%, a significant increase from 4% in 2020 and 9% in 2021. The related study demonstrates the increasing demand for EVs as environmentally friendly alternatives in the global automotive market.

The EV ecosystem is evolving in parallel with the acceleration in the adoption of EVs. This ecosystem is composed of various components, including (i) EVs, (ii) charging infrastructure, (iii) energy sources, (iv) batteries, (v) testing systems, (vi) policies, and (vii) recycling. The charging infrastructure, a crucial component of the EV ecosystem comprises (i) charging stations, (ii) charging networks, (iii) payment and management systems, and (iv) compatibility and standards (LaMonaca and Ryan, 2022). The charging stations, particularly AC and DC fast charging stations, are currently subjects of extensive academic and commercial research. DC fast charging stations, with their high power and rapid charging capabilities, facilitate faster adoption of EVs, allowing users to travel without range or charging concerns. Designed for various power levels, these stations

typically range from 50-100-150 kW in urban and rural areas, 100-350 kW at highway rest areas, and 350 kW and above along main highways (Rafi and Bauman, 2021; Deb et al., 2021).

Due to the high installed power and instantaneous high power demands of DC fast charging stations, it is likely that they may adversely affect the local power grid. This situation can lead to the rapid reaching of power limits on the grid, causing power quality issues and grid fluctuations that can negatively impact the operation of other loads. In regions where the local power grid infrastructure is old and weak, the installation of DC fast charging stations poses challenges (Franzese et al., 2023). As strengthening the existing grid infrastructure is both costly and time-consuming, such issues can be addressed by systems capable of locally storing electricity, such as energy storage systems. To prevent these problems and enhance grid reliability, DC fast charging stations equipped with battery storage units have been developed. The key advantages provided by these systems include preventing grid fluctuations and balancing instantaneous high power demands. Additionally, they offer the possibility of integrating renewable energy sources into the system.

There are limited academic studies on the use of batteries as a buffering unit in developing charging stations. In (Bowen et al., 2022), studies have been conducted on charging patterns, revealing a correlation between the hours at which EVs connect to charging stations and the average energy transfer. Particularly in the evening hours, around 20:00, there is an increase in charging sessions with higher energy demands. In this regard, a simulation study has been conducted and verified, examining the effectiveness of battery buffers in facilitating fast charging of EVs with reduced grid capacities. Authors in (Rufer and Fernandez, 2018) focus on an external bidirectional battery buffering unit. The respective system is equipped with DC-DC and AC-DC converters for the battery buffer group and is connected to the grid instead of directly to the charging station. This creates a need for converters on both the charging station and the battery buffer system sides. Battery-buffered fast charging stations aim to limit the power drawn from the grid to prevent strain on the existing grid infrastructure. In this regard, the capacity calculation of the integrated buffer batteries is crucial to ensure uninterrupted charging of electric vehicles. Authors in (Bryden et al., 2019) propose a method based on the acceptable average waiting time of drivers at a fast charging station to size a fixed energy storage system. The economic viability of an energy storage system (ESS) solution to be integrated for the buffering application of fast charging stations is another challenging issue. In this context, authors (Sockeel et al., 2021) have analyzed the economic viability of a buffer battery by considering the calendar and cyclic aging of the energy storage system, the overall efficiency of fast charging, operational expenses (OPEX), capital expenses (CAPEX), and the purchase price of grid electricity.

As understood from the literature review, high-power EV charging stations used in weak grids incorporate battery energy storage systems to rapidly charge vehicles. This system enables EVs to meet their energy demands and rapidly charge by utilizing the stored electricity in the battery. The buffer battery can be recharged at a slower rate from grid sources or renewable energy-based distributed generation during periods of lower electricity demand. This allows for a more balanced management of energy consumption and the utilization of local resources to meet the fast-charging demands of electric vehicles.

In this study, simulation studies and performance analysis of an integrated battery-buffered DC fast charging station with dual EV connections have been conducted. The rest of the paper is organized as follow: Section II introduces the power circuit and control scheme of the system. The performance results of the system are presented in Section III Section IV puts forward conclusions with relevant discussion.

Power Circuit and Control Scheme

The power circuit configuration of the battery-buffered DC fast charger system is illustrated in Figure 1. The system is composed of a three-phase voltage source converter, an isolated unidirectional DC-DC converter, and a buffer battery. The three phase grid converter (also known as the front-end converter) is limited to a power transfer capacity of 30 kW. Additionally, with bidirectional power transfer capability, it is able to charge both the EVs and the buffer battery, as well as provide voltage and frequency support from the buffer battery to the grid. The unidirectional DC-DC converter consists of an H-bridge converter, a high-frequency transformer, and a diode rectifier. The relevant converter unit enables fast charging of EVs with a power transfer capacity of 150 kW. The system integrates the converters with a 186 kWh buffer battery.

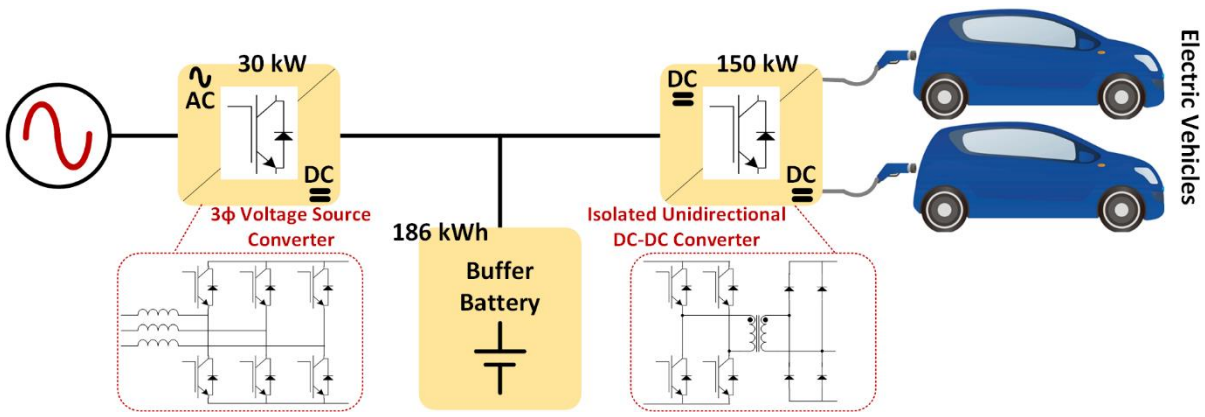

Figure 1. Power circuit of battery-buffered DC fast charger

The control scheme of the system is shown in Figure 2. The main aims of the overall controller scheme are: (i) to charge the EVs with CC and CV charging algorithms, (ii) to limit the grid side power flow, (iii) to charge buffer battery from the grid, and (iv) to buffer the grid with battery. The control scheme developed for the stated objectives, as seen in Figure 2, is equipped with DC link control on the grid converter side and CC-CV control algorithms on the DC-DC converter side. The system operates adaptively and allows instantaneous switching between the control loops.

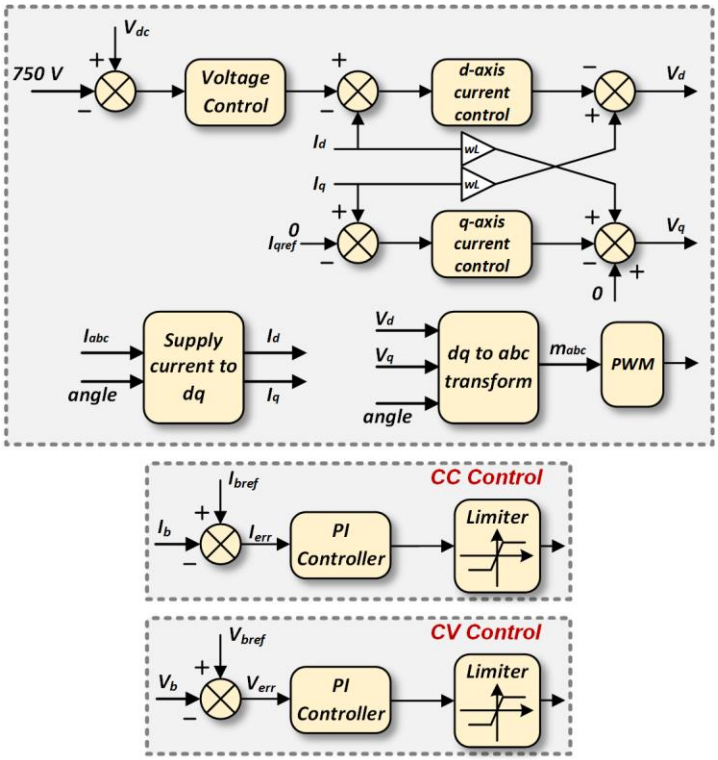

Figure 2. Control scheme of the DC fast charger

Performance Results

In order to investigate the performance of the battery-buffered DC fast charger under two EVs connection condition, a simulation model has been developed in MATLAB/Simulink environmenet. The parameters of the system is given in Table 1.

Table 1. Parameters of the system

Parameters	**Values**
Fast Charge Power	150 kW
AC Input Voltage Range	260 Vac ~485 Vac, 45 Hz~65 Hz, nominal 400 Vac, 50 Hz
Battery Voltage Range	575 Vdc~750 Vdc
DC Output Voltage Range	150 Vdc~1000 Vdc
Maximum Output Current	500 A
Mains Rectifier Maximum Power	30 kW
System Total Efficiency	> %92

The DC link voltage, which provides the connection for the battery, grid converter, and DC-DC converter, is 750 V, and the charging voltage of EVs is 900 V. The buffer battery is designed with a capacity of 186 kWh and 280 Ah. The grid converter power is limited to 30 kW, and the DC-DC converter is set at 150 kW. Simulation tests have been conducted for the case where the buffer battery meets the majority of the charging power while drawing limited power from the grid and for the scenario where the relevant product supplies power to the grid. As evident from Figure 3, when a single EV is connected to the station, the buffer battery provides grid support and charges the EV. However, when an additional EV is connected to the station (at 0.1 seconds), power is drawn from both the battery and the grid to charge the vehicles. As observed from the waveforms, in the time interval of 0.02-0.1 seconds, the battery pack supplies approximately 120 kW of power. About 90 kW of this power is used to charge the vehicle, while approximately 30 kW comes from the grid. After 0.1 seconds, with the initiation of charging for an additional electric vehicle, the battery pack supplies 154 kW, and approximately 30 kW is drawn from the grid, ensuring that two vehicles are charged with power values of 90 kW + 90 kW.

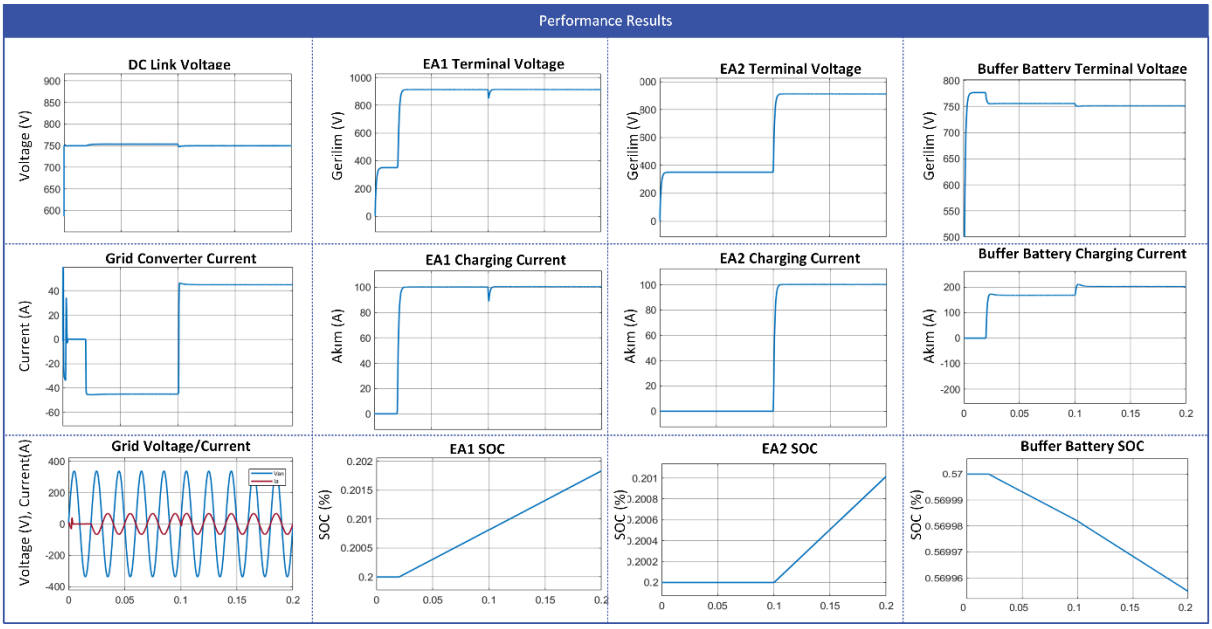

Figure 3. Performance results

Conclusion

This study conducts a performance analysis of a DC fast charging station equipped with a buffer battery under the condition of connecting two vehicles. The primary perspective of the presented system includes (i) fulfilling the majority of the target charging power demand through the buffer battery, (ii) reducing the grid load, (iii) charging the buffer batteries at appropriate time intervals, and (iv) providing grid voltage and frequency support through the buffer batteries. For these objectives, 150 kW battery-buffered DC fast charger modeling has been carried out in the MATLAB/Simulink environment, and the system performance has been validated under dynamic conditions.

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A NOVEL APPROACH TO EXTEND THE BATTERY LIFE BY CHARGING MANAGEMENT CONSIDERING THE CELL TEMPERATURE

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ABSTRACT

Batteries, which have a wide range of uses from electric vehicles to smartphones and have become an indispensable part of our daily lives, are adversely affected by extreme temperature conditions, and their aging and capacity loss accelerate significantly. While the chemistry of the batteries deteriorates more quickly under stress at high temperatures, efficiency, and capacity loss are experienced at low temperatures. An improved battery management system (BMS) design is required to minimize the effect of temperature on the battery and to use the battery efficiently. The BMS to be designed must continuously monitor the ambient and cell temperature to protect against thermal extremes, take precautions before the problem occurs, or perform system control by considering these parameters. Therefore, a temperature-conscious management system improves safety and increases battery life and reliability in applications requiring high performance and endurance. The proposed study presents a BMS design in which temperature is used as a control input, and the charging rate is varied accordingly to extend battery life and improve safety. Proposed approach is based on analyzing how temperature changes and charging rates affect cell aging and capacity degradation and understanding the thermal effects on battery chemistry. The simulation study results show that the proposed BMS can provide operational safety under high efficiency while significantly extending the battery life. Considering two situations that create chemical stress on the battery, the BMS aims to minimize the stress by reducing the C-Rate value in case of an increase in temperature. In this way, it has been shown that the total amount of energy obtained from the battery is significantly increased.

Keywords: Lithium batteries, Battery management systems, Renewable energy sources, Energy storage, Batteries.

Introduction

Batteries serve as the energy source of many devices that are indispensable parts of our daily lives and are used in a wide range of applications, from electric vehicles to smartphones (Cordella et al., 2021; Ribeiro da Silva et al., 2023; Ye et al., 2023). They also provide continuity for renewable energy sources and play an essential role in a stable energy transfer. In this respect, batteries also offer significant benefits in terms of environmental protection. They contribute to reducing carbon emissions and global warming by reducing dependence on fossil fuels(Castelletto & Boretti, 2022; Deguenon et al., 2023a; Mérida García et al., 2024). As our need for batteries is increasing daily, our need for batteries to serve longer is also growing.

Battery management systems (BMS) are being developed for the longer life of batteries. BMS optimizes the performance and safety of batteries and ensures their optimum use(Waseem et al., 2023). Continuously monitoring and controlling the parameters considered in its design prevents overcharging, discharging or overheating. This increases energy efficiency while extending battery life (Deguenon et al., 2023b). These BMSs can use many parameters as input and output. Parameters such as current, voltage, state of charge, charge rate, health status, temperature, and combinations can control input and output (Hussain, Ali, Park, et al., 2019). Although temperature, one of these parameters, directly affects battery chemistry and life, it is often ignored in BMS designs(Kumar & Goel, 2023).

Variable temperature scenarios in extremely low and extremely high-temperature environments significantly increase battery capacity loss(Apribowo et al., 2022; Chavan et al., 2023). Batteries used in these environments without taking precautions cannot perform fully as well as aging rapidly. For example, when used at high temperatures, the battery is under stress, and chemical breakdown accelerates. On the other hand, low temperatures prevent the battery from utilizing its full capacity(Wang et al., 2022). As a result, temperature should not be ignored when designing an advanced BMS.

In (Lu et al., 2019), the responses of the battery to C-Rate values under different temperatures were experimentally demonstrated. The effect of the heat generated by the battery on the charge/discharge characteristics was also investigated. According to the study, it is proved that the optimal C-Rate value changes at each temperature. (Hussain, Ali, Nengroo, et al., 2019) is another study in which temperature is used as a direct control parameter in addition to the primary control mechanism and has an active effect on charge/discharge rates. To reduce the stress caused by temperature, the reference current value was divided into three different regions depending on the temperature. As a result of the study, the system efficiency was measured as 97.6%.

In the proposed study, a rule-based BMS is designed to use different charging rates in different temperature environments to increase the battery life. Battery charging rate also has a significant impact on battery health. Although high-speed charging technologies seem to provide advantages in terms of time, they cause considerable damage to battery chemistry. The proposed study aims to reduce one of the two factors that adversely affect battery health when one of them increases. Thus, it is desired to balance the stress caused by the increase in temperature by reducing the stress caused by the charging rate.

Materials and Methods

For the type of lithium-ion battery, the effect of the temperature on the model's parameters is represented by the following equations. The equations for the charge and discharge model are analyzed separately. Firstly, the equations for the discharge model are given in equations 1 and 2.

$$\mathrm{f}_1(\mathrm{it}, \mathrm{i}*, \mathrm{i}, \mathrm{T}, T_a) = E_0(T) - K(T) \cdot \frac{Q(T_a)}{Q(T_a) - it} \cdot (i* + it) + A \cdot exp(-B \cdot it) - C \cdot it \tag{1}$$

$$V_{batt}(T) = f_1(\mathrm{it}, \mathrm{i}*, \mathrm{i}, \mathrm{T}, T_a) - R(T) \cdot i \tag{2}$$

The following equations are given for the charging model.

$$\mathrm{f}_1(\mathrm{it}, \mathrm{i}*, \mathrm{i}, \mathrm{T}, T_a) = E_0(T) - K(T) \cdot \frac{Q(T_a)}{it + 0.1 \cdot Q(T_a)} \cdot i* - K(T) \cdot \frac{Q(T_a)}{Q(T_a) - it} it + A \cdot exp(-B \cdot it) - C \cdot it \tag{3}$$

$$V_{batt}(T) = f_1(\mathrm{it}, \mathrm{i}*, \mathrm{i}, \mathrm{T}, T_a) - R(T) \cdot i \tag{4}$$

Then, to include the effect of battery temperature in the battery model, the thermodynamic voltage E_0, polarisation constant K, and internal resistance R are calculated according to Nernst and Arrhenius(Troxler et al., 2014).

$$E_0(T) = E_0 \mid T_{ref} + \frac{\partial E}{\partial T}(T - T_{ref}) \tag{5}$$

$$K(T) = K \mid T_{ref} \cdot exp\left(\alpha\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right) \tag{6}$$

$$Q(T_a) = Q \mid T_a + \frac{\Delta Q}{\Delta T} \cdot (T_a - T_{ref}) \tag{7}$$

$$R(T) = R \mid T_{ref} \cdot exp\left(\beta\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right) \tag{8}$$

Where C is the nominal discharge curve slope, T is the cell temperature, T_a is ambient temperature, E/T is the temperature coefficient of reversible voltage, α and β are the Arrhenius rate constants for the polarization resistance and internal resistance respectively, $\Delta Q/\Delta T$ is the maximum temperature coefficient of the capacitance, T_{ref} is the ambient temperature (Motapon et al., 2020). The relationship between temperature internal resistance and power loss is also given in equation 9.

$$\mathrm{T}(t) = L^{-1}\left(\frac{P_{loss}R_{th}T_a}{1 + s \cdot t_c}\right) \tag{9}$$

Where R_{th} is temperature-dependent resistance, t_c is the temperature-based time constant, P_{loss} is the power loss because of the heat generation. Finally, N in the expression expresses the number of battery cycles. As can be seen, there is a direct connection with both temperature and C-Rate. The proposed study is based on the relationship between these two parameters and their effect on battery cycle life.

$$N(n) = H\left(\frac{DOD(n)}{100}\right)^{-\xi} \cdot exp\left(-\psi\left(\frac{1}{T_{ref}} - \frac{1}{T_a(n)}\right)\right) \cdot \left(I_{dis_ave}(n)\right)^{-\gamma_1} \cdot \left(I_{ch_ave}(n)\right)^{-\gamma_2} \tag{10}$$

Proposed Temperature-Based Battery Management System

A novel rule-based control algorithm has been presented in this study. It aims to extend the lifetime of lithium-ion batteries. The rates of charge and discharge, known as C-rates, are dynamically controlled in response to changes in temperature. It's well known that temperature significantly impacts the degradation processes of lithium-ion batteries. Adjusting C-rates to real-time temperature data aims to mitigate the adverse effects of temperature extremes on battery health.

The simulation study carried out battery tests under varying cell and ambient temperatures. Temperature values were continuously monitored throughout the study, and temperature changes were used as the control input to adjust the C-Rate value. The algorithm's decision-making process is organized as a rule table based on the temperature ranges: 25 to 35 °C, 35 to 45 °C and above 45 °C. The simulation maintains a standard C-rate for temperatures between 25°C and 35°C, suitable for normal operating conditions. Between 35°C and 45°C, the C-rate is reduced to decline the increased thermal stress on the battery. Above 45°C, the C-rate is reduced twice to maintain the battery's longevity.

The efficiency of the proposed scheme has been tested with realistic simulation studies. In these simulation studies, battery behaviour under varying operating conditions is investigated. The results obtained are compared with standard methods, demonstrating their superiority.

A detailed analysis of the data obtained from the simulation studies has been carried out to examine the proposed study's effect on battery life and capacity loss. The total energy that can be withdrawn during the battery life is taken as a performance indicator. The results obtained revealed the success of the study.

Findings and Discussion

Firstly, simulation studies were carried out to show the effect of temperature on the battery by keeping all other conditions equal and changing only the temperature. The data on the battery used is given in Table 1. The results obtained are shown in Figure 1.

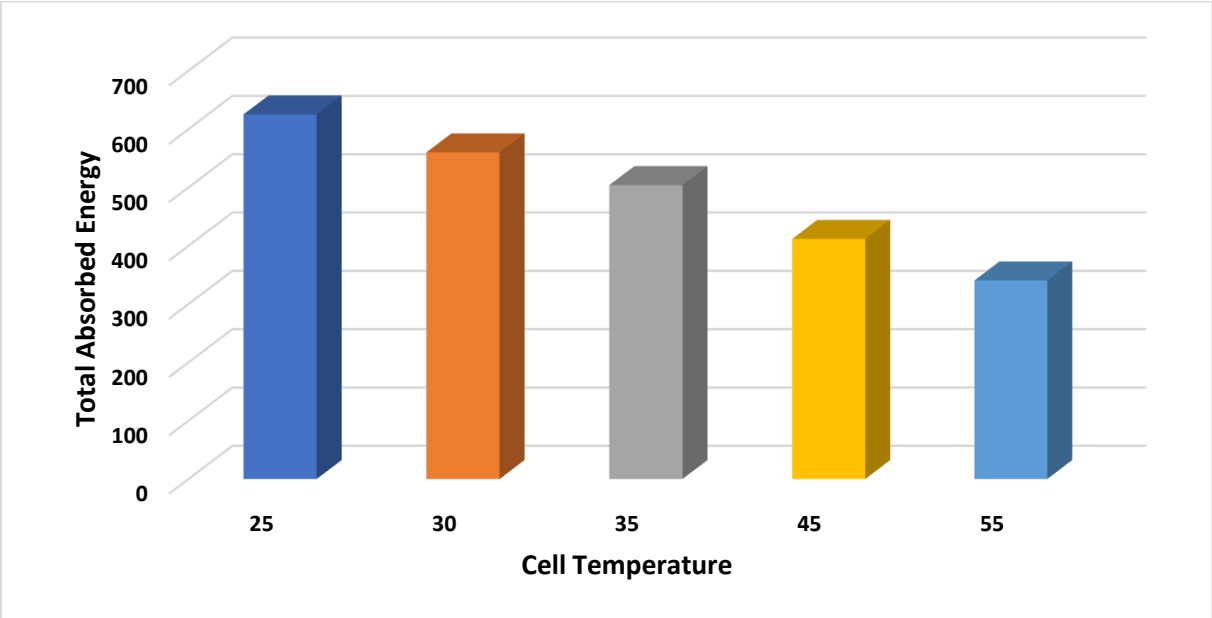

Figure 1. Total absorbed energy under varying cell temperature

As a result of the simulation study, the effect of temperature on the battery is seen. The battery ages rapidly due to the chemical stress caused by the temperature, and the associated capacity loss is experienced. The total energy extracted from the battery at 25 degrees, accepted as the standard temperature, was measured as 625.03 kWh. This value decreased by 34.12% and was measured as 411.75 kWh at 45 degrees. When the temperature increases to an extreme point, such as 55 degrees, only 340.47 kWh of energy can be extracted, with a decrease of 45.52%.

Table 1. Battery Parameters

Parameter	Value
Nominal Voltage	12,6 V
Initial Capacity	40 Ah
Nominal Current	20 A (0,5C)
End of Life Capacity	40*0,8 Ah
Nominal Charge Current	20 A (0,5C)
Depth of Discharge	80

The second simulation study analyzed the effect of C-Rate parameter on battery aging. Figure 2 compares the total energy obtained from the battery in simulation studies with different C-Rates.

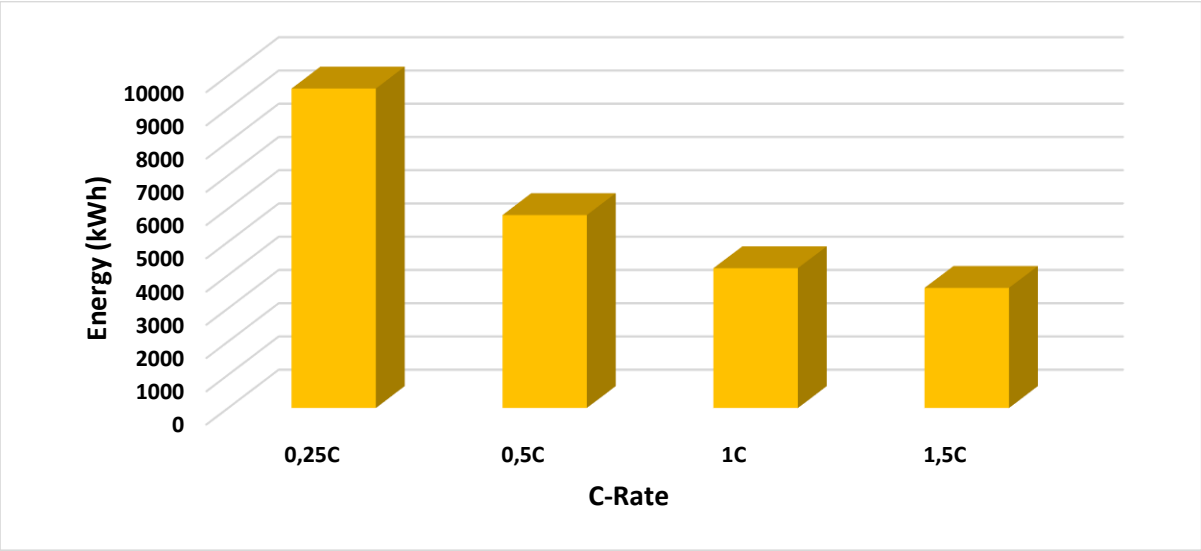

Figure 2. Total absorbed energy under varying cell C-Rate

In the scenario performed under 1.5C, the total amount of energy extracted decreased by 60.12% compared to the scenario performed with 0.25C. As a result of the simulation study, the effect of the C-Rate parameter on battery capacity and life is seen. The battery ages very quickly due to the chemical stress caused by rapid charging and the temperature pressure it creates. As can be seen, as the C-Rate increases, the battery approaches the deep discharge state, and the total energy obtained from the battery decreases.

In light of the simulation studies and the theoretical information in the literature, it is seen that both C-Rate and temperature parameters have a high stress and aging effect on the battery. The proposed study aims to prevent these two parameters from affecting the battery simultaneously and to reduce the C-Rate parameter to dampen the stress caused by the temperature increase. The results of the simulation study are given in Figure 3.

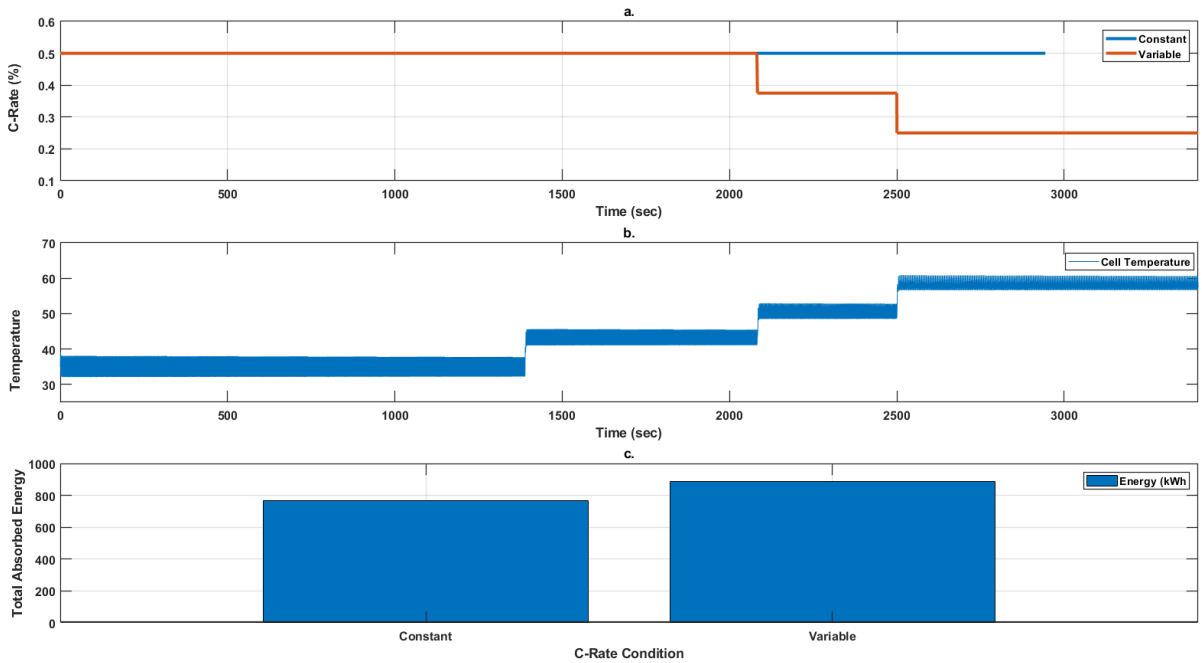

Figure 3. Simulation results of the proposed study

The standard BMS, in which only the temperature is changed while leaving all other conditions the same, and the proposed BMS, in which the C-Rate parameter is also varied depending on the temperature, are compared

throughout the lifetime of the battery system controlled by SBMS, a total of 765.6 kWh of energy was extracted. The total energy absorbed from the same battery system managed with the suggested study was 15.64 % higher, measuring 887.65 kWh/hr.

Conclusion and Recommendations

In this study, a BMS where temperature is at the forefront is developed. The relationship between cell temperature, charge rate and battery aging shows that the battery life is extended thanks to the proposed work, which provides a charge rate that varies depending on the cell temperature. The proposed study can be effective in various applications, from electric vehicles to renewable energy, where battery life and efficiency are essential.

Simulation studies were carried out for the proposed research using the Matlab/SIMULINK program. C-Rates for three different temperature zones are designed. While the standard C-Rate is used between 25-35 degrees, the C-Rate is reduced by 25% in the 35-45 degrees range. This way, the stress caused by the battery's temperature is minimized. In the 45-55 degrees range, the desert temperature, C-Rate, is reduced by 50% compared to the first case. Batteries are under much more high chemical stress in these temperature ranges. The proposed approach aims to suppress this stress.

The simulation studies compare the standard battery management system (SBMS) and the proposed battery management system with temperature-varying charge rates. A total of 765.6 kWh of energy could be extracted from the battery system controlled by SBMS during its entire lifetime. The total energy withdrawn from the same battery system controlled by the proposed study was increased by 15.64% and measured as 887.65 kWh. Simulation studies demonstrate the superiority of the proposed study.

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ELAZIĞ İLİNİN BİTKİSEL BİYOKÜTLE POTANSİYELİ

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ÖZET

Hızlı nüfus artışı, sanayi ve teknolojide görülen değişim ve büyüme, enerji talebinin tüm dünyada olduğu gibi ülkemizde de artmasına sebep olmuştur. Bugün hala birincil enerji kaynağı olarak fosil yakıtlar kullanmaktayız. Ancak dünyamıza verdiği zarar ve tükeneceği ön görüsü fosil yakıtların yerini yenilenebilir ve zengin kaynaklara sahip alternatif enerji kaynaklarının alması gerektiğini işaret etmektedir.

Günümüz enerji sistemlerinin büyük çoğunluğu hala fosil yakıtlar kullanmaktadır. Var olan sistemlerin dönüşümü, dönüşemiyorsa yeniden kurulumunun belirli bir zaman gerektireceği ve elbette ki yeterli teşviklerle mümkün olabileceği açıktır. Bu sistemsel geçişe öncülük edebilecek, kaynak veri oluşturabilecek çalışmaların varlığı bu sebeplerle çok önemlidir.

Alternatif enerji kaynakları içinde doğaya zarar vermemesi, ulaşılabilirliği, yenilenebilirliği, sürdürülebilirliği ile yenilenebilir enerji kaynakları ön plan çıkmaktadır. Yenilenebilir enerji kaynaklarından biri olan biyokütle enerjisi, canlı ya da ölü bütün organik canlılardan elde edilmektedir. Bereketli toprakları, güneşli gün sayısının fazlalığı ve zengin su kaynakları ile Türkiye tam bir tarım ülkesidir. Biyokütle enerjisi bakımından da oldukça zengindir. Bu çalışmada Türkiye'nin Doğu Anadolu bölgesinde yer alan Elazığ ilinin bitkisel biyokütle potansiyeli incelenmiştir. Çalışmada Elazığ da hasat edilmiş baklagiller, yumru bitkiler, yağlı tohumlar, endüstriyel bitkiler ve yem bitkileri kullanılmıştır. Veriler 2021 yılına ait olup TÜİK'den elde edilmiştir. Bahsi geçen ürünlerin hasadı toplamda 1.360.160 dekarlık bir alanda yapılmıştır. Alınan veriler işlenerek enerji değerleri hesaplanmıştır. 85.195,2 TEP değeri ile tahıllar, ilin en yüksek bitkisel biyokütle potansiyeline sahiptir. Daha sonra sırasıyla endüstriyel bitkiler, yumru bitkiler, baklagiller, yem bitkileri ve yağlı tohumlar gelmektedir. Elazığ ilinin toplamda bitkisel biyokütle potansiyeli ise $0{,}2.10^7$ MWh'dir. Türkiye için Elazığ ilinin bitkisel biyokütle potansiyeli dikkate değerdir.

Anahtar kelimeler: Yenilenebilir enerji kaynakları, Biyokütle enerjisi, Bitkisel biyokütle potansiyeli, Türkiye-Elazığ

PLANT BIOMASS POTENTIAL OF ELAZIĞ PROVINCE

ABSTRACT

Rapid population growth, change and growth in industry and technology have led to an increase in energy demand in our country as in the whole world. Today we still use fossil fuels as the primary source of energy. However, the damage it causes to our world and the prediction that it will run out indicate that fossil fuels should be replaced by renewable and resource-rich alternative energy sources.

The vast majority of today's energy systems still use fossil fuels. It is clear that the transformation of existing systems, or if not, their re-installation, will require a certain amount of time and can only be possible with adequate incentives. The existence of studies that can pioneer this systemic transition and create source data is very important for these reasons.

Among alternative energy sources, renewable energy sources come to the forefront with their accessibility, renewability and sustainability. Biomass energy, one of the renewable energy sources, is obtained from all organic organisms, living or dead. Turkey is an agricultural country with its fertile soils, high number of sunny days and rich water resources. It is also rich in biomass energy. In this study, the plant biomass potential of Elazığ province located in the Eastern Anatolia region of Turkey was investigated. Legumes, tuber crops, oilseeds, industrial plants and forage crops harvested in Elazığ were used in the study. The data belongs to

2021 and was obtained from TUİK. These crops were harvested in a total area of 1.360.160 decares. Energy values were calculated by processing the received data. With 85.195.2 TOE, cereals have the highest plant biomass potential in the province. Industrial crops, tuber crops, legumes, fodder crops and oilseeds follow respectively. The total plant biomass potential of Elazığ province is $0.2.10^7$ MWh. For Turkey, the plant biomass potential of Elazığ province is remarkable.

Keywords: Renewable energy sources, Biomass energy, Plant biomass potential, Türkiye-Elazığ

Giriş

Türkiye gelişmekte olan bir ülkedir. Nüfusu artarken sanayisi ve teknolojisi de ilerlemektedir. Yenilenemez enerji kaynakları incelendiğinde Türkiye'de büyük miktarda düşük kaliteli linyit yataklarının olduğu görülmektedir. Doğalgaz, petrol, kaliteli kömür bakımından ise oldukça yetersizdir. Yenilenebilir enerji kaynakları bakımından en çok hidrolik enerjiden faydalanılmaktadır. Fosil kaynakları yetersiz olan ülkemiz yenilenebilir enerji kaynaklarını ise tam bir verimle kullanamamaktadır. Bu sebeple enerji talebinin büyük bir kısmını dışarıdan temin etmek durumundadır.

Alternatif enerji kaynakları içinde doğaya zarar vermemesi, ulaşılabilirliği, yenilenebilirliği, sürdürülebilirliği ile yenilenebilir enerji kaynakları ön plana çıkmaktadır. Günümüz enerji sistemlerinin büyük çoğunluğu hala fosil yakıtlar kullanmaktadır. Var olan sistemlerin dönüşümü, dönüşemiyorsa yeniden kurulumu belirli bir zaman gerektirecektir. Bunun yanında yeterli teşvik ve finansmana da ihtiyaç duyulacağı açıktır. Dünyada yenilenebilir enerji kaynaklarının kullanımı için teşvik oluşturabilecek finansal araçlar üzerinde kendini geliştirirken ülkemizin de bu yolu takip ederek yeterli teşvik ve finansı sağlamasının gerekliliği ortadadır (Ergün H.O. ve Şahin B., (2023)). Bu sistemsel geçişe öncülük edebilecek, kaynak veri oluşturabilecek çalışmaların varlığı ise bu sebeplerle çok önemlidir.

Güneşli gün sayısının fazlalığı, üç tarafının sularla çevrili olması, zengin yer altı ve yer üstü kaynakları göz önüne alındığında Türkiye yenilenebilir enerji kaynakları bakımından varlıklı bir ülkedir. Tarımda ve hayvancılıkta aktif varlığı ve köklü bir geçmişinin oluşuyla da biyokütle enerjisi bakımından yüksek bir potansiyeline sahiptir. Bir işletmenin en büyük girdisi enerji iken enerjisini dışarıdan sağlayan bir ülke sanayisinin gelişse de yeterince kar elde edemeyeceği açıktır. Bu nedenle var olan yenilenebilir enerji potansiyelinin tespiti ve kullanımı oldukça önemlidir. Literatürde, Türkiye'nin bitkisel biyokütle potansiyeli tespiti üzerine çalışmalar yapılmıştır. Kurt, G. ve Koçer, N.N., (2010), Malatya ilinin biyokütle potansiyelini araştırmışlardır. Şehrin kuru biyokütle potansiyelini 1.596.786,4 TEP olarak hesaplamışlardır. Kuş vd., (2016), Iğdır ilinin 2009-2013 yılları arasında tarımsal biyokütle potansiyelini araştırmışlardır. Şehrin biyokütle potansiyelinin 220 milyon TEP (ton eşdeğer petrol) olduğunu saptamışlardır. Demir vd. (2016), Erzincan şehrinin, 2006-2015 yılları arasında tarımsal biyokütle enerjisi potansiyelini incelemişlerdir. Toplam da 14.292 MW tarımsal biyokütleye sahip olduğunu tespit etmişlerdir. Kulcu (2016), 2015 yılı için Afyonkarahisar şehrinin, tarımsal biyokütle potansiyelini araştırmış, 323.841 TEP enerji potansiyeli olduğunu hesaplamıştır. Karaca vd. (2016), TÜİK' den aldıkları 2014 yılı veriler ile Aydın şehrinin tarımsal biyokütle potansiyelini araştırmışlardır. Şehrin toplam 11.365.506 GJ enerji değerine sahip olduğunu görmüşlerdir. Demir (2017), Kars ilindeki biyokütle enerji potansiyeli incelemiş, biyokütle enerjisi ile elde edilebilecek elektrik üretim potansiyelini ise 361.488 MWh/yıl olarak bulmuşlardır. Akbaş (2019), Aydın şehrinin 2009-2018 yılları TÜİK verileri ile tarımsal biyokütle potansiyelini incelemiş, Aydın ilinin Türkiye'nin biyokütle enerji potansiyelinin % 1.77'sine sahip olduğunu görmüştür. Karabaş (2019), Sakarya şehrinden alınan 2017 yılı TÜİK verileri ile bitkisel biyokütle potansiyelini araştırmış, şehrin toplam bitkisel biyokütle enerjisi değerini 566.096.472 GJ/yıl olarak hesaplamıştır.

Bu çalışmada, Elazığ ilinin bitkisel biyokütle potansiyeli araştırılmıştır. TÜİK'den (Türkiye İstatistik Kurumu) Elazığ iline ait 2021 yılı verileri alınmıştır (TUİK, 2022). Bitkisel biyokütle potansiyelini hesaplayabilmek için; tahıllar, baklagiller, yumru bitkiler, yağlı tohumlar, endüstri bitkileri ve yem bitkileri verileri ayrı ayrı alınmış, kategorize edilerek toplam ekili alanları hesaplanmıştır. Ekili alanlardan elde edilen ürünlerin enerji değerleri hesaplanarak tablo ve grafik halinde sunulmuştur. Şehrin toplam bitkisel biyokütle potansiyeli verilmiştir.

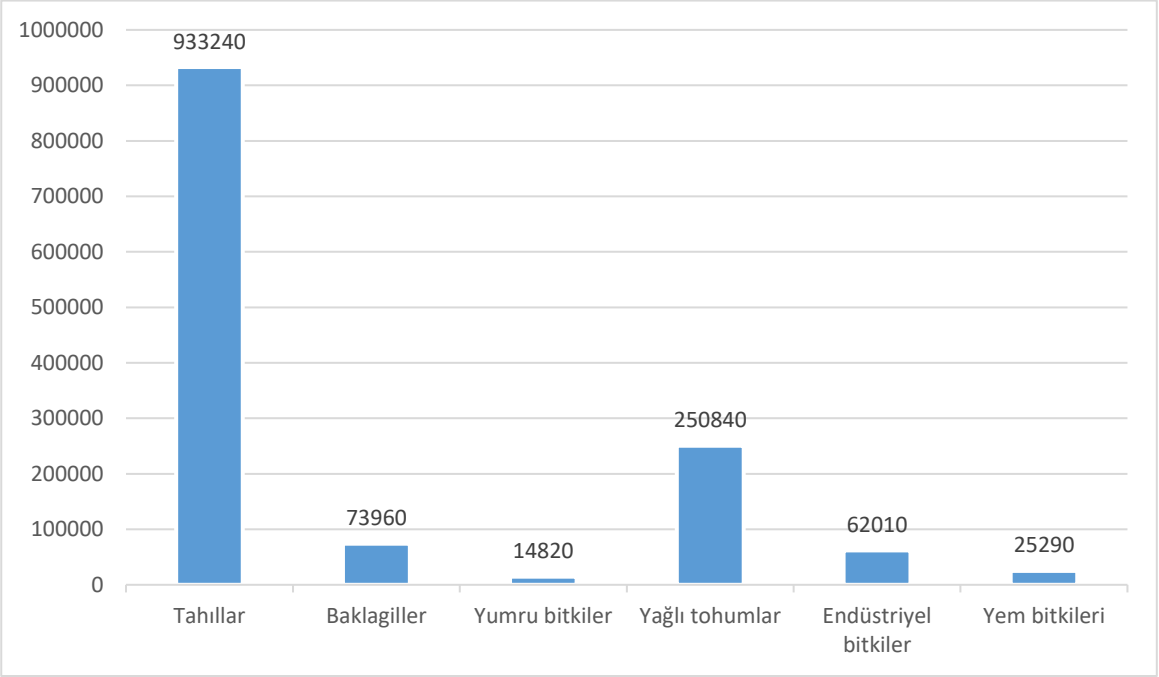
Materyal ve Metot

Elazığ ili Doğu Anadolu bölgesinin güneybatısında yer almaktadır. Toplam yüz ölçümü 9.153 km^2'dir. Ekonomisi tarım ve hayvancılığa dayanmaktadır. Topraklarının çok büyük bir kısmı sulanabilir, tarıma elverişli topraklardan oluşmaktadır. İlçelerinde ki nüfusun büyük çoğunluğu tarımla geçinmektedir. Elazığ da en çok tahıl grubu yetiştirilmektedir. Yetiştirilen tahıllar; buğday, arpa, mısır ve çeltiktir. Baklagiller; nohut, kuru fasulye, kırmızı - yeşil mercimek, bamya, bakla ve mürdümdür. Yumru bitkiler; patates, soğan, sarımsak, pırasa, havuç ve turptur. Yağlı tohumlar; susam, çiğit, fındık, ceviz ve antepfıstığıdır. Endüstriyel bitkiler; şeker pancarı ve pamuktur. Yem bitkileri ise fiğ, burçak, yonca ve korungadır.

Bu çalışma da Elazığ ilinin bitkisel biyokütle potansiyeli incelenmiştir. Bitkisel biyokütle potansiyelini belirlemek için il de yetiştirilen tahılların, baklagillerin, yumru bitkilerin, yağlı tohumların, yem bitkilerinin ve endüstriyel bitkilerin verileri TÜİK' den alınmıştır. Veriler 2021 yılına aittir. Kategoriler halinde ele alınan bitkisel biyokütlelerin ekili alanları dekar cinsinden hesaplanmıştır. Her kategorinin kendi içindeki potansiyel enerji değerini hesaplamak için üretilen ürünün tonunun kuru biyokütle potansiyelinin ortalama 4000kcal ısıl değerde olduğu kabul edilmiştir (Kurt, G. ve Koçer, N.N., (2010)). Üretilen ürünün miktarı üzerinden enerji değeri hesaplandıktan sonra 1kcal 10^{-7} TEP (ton eşdeğer petrol) olarak 1 TEP 0,01163 MW alınarak hesaplamalar yapılmıştır. Sonuçlar tablo ve grafiklerle açıklanmıştır.

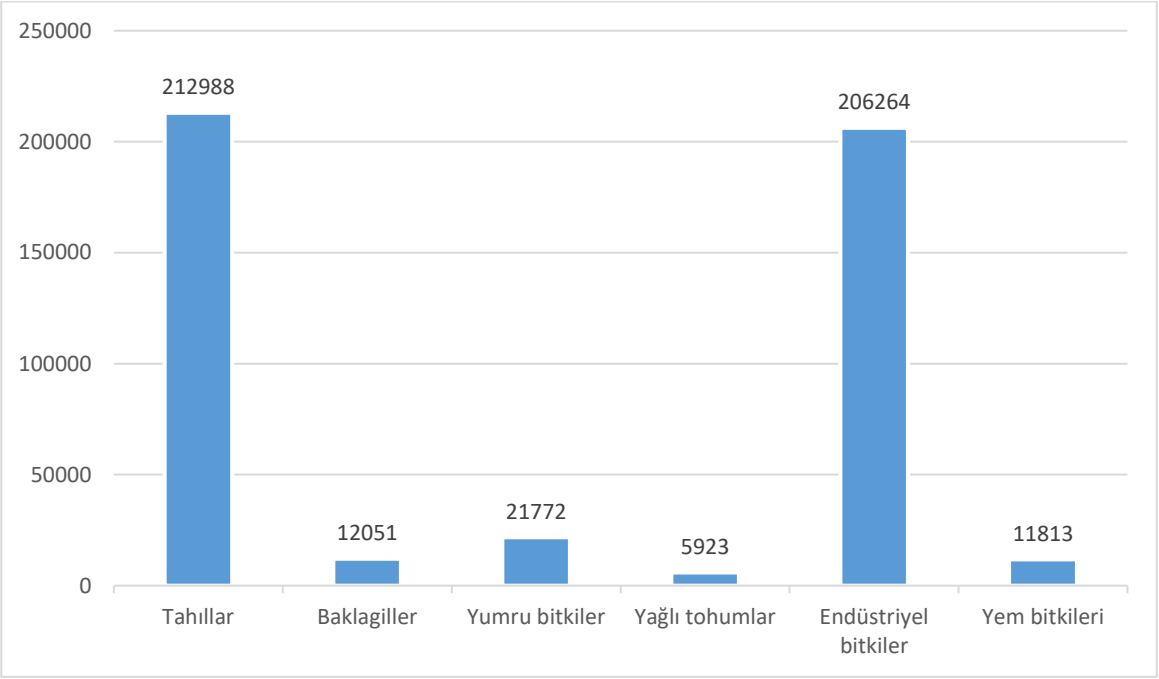
Bulgular ve Tartışma

Elazığ iline ait bitkisel biyokütle potansiyelini belirlemek için 2021 yılına ait veriler TÜİK'den alınmıştır. Yetiştirilen bitkiler tahıllar, baklagiller, yumru bitkiler, yem bitkileri, endüstriyel bitkiler ve yağlı tohumlar olarak kategorilendirilmiştir. Ekili alanın toplam ölçümü verilmiştir. Üretilen ürünlerin tonları üzerinden hesaplar yapılarak enerji değeri hesaplanmıştır. Veriler aşağı da tablo ve şekiller ile gösterilmiştir.



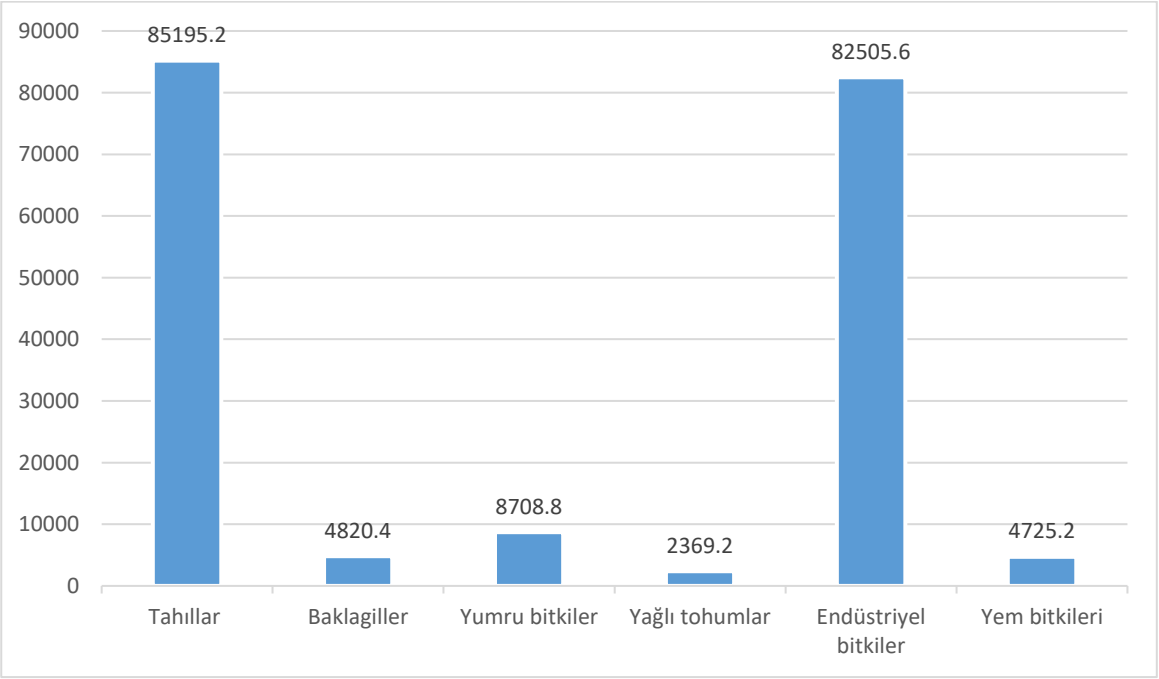
Şekil 1: 2021 TÜİK verilerine göre Elazığ da ekili alan dağılımı (Dekar)

Şekil 1'de Elazığ ilinde bitkisel biyokütle potansiyeli olan, tahılların, baklagillerin, yumru bitkilerin, yağlı tohumların, endüstriyel bitkilerin ve yem bitkilerinin ekili oldukları alan dağılımı Dekar olarak görülmektedir. Şehrin güneşli gün sayısının etkisiyle tahıl ekimine uygun olduğu dolayısıyla açık ara en çok tahıl ekiminin yapıldığı görülmektedir. Toprak yapısı dikkate alındığında ise yumru bitkilerin en az oranda ekildiği izlenmektedir. Tahıl ekimi başta olmak üzere sırasıyla yağlı tohumlar, baklagiller, endüstriyel bitkiler, yem bitkileri ve yumru bitkilerin ekildiği grafikten okunmaktadır.



Şekil 2: 2021 TÜİK verilerine göre Elazığ da yetiştirilen ürünlerin hasat dağılımı (Ton)

Şekil 2'de Elazığ ilinde bitkisel biyokütle potansiyeli olan, tahılların, baklagillerin, yumru bitkilerin, yağlı tohumların, endüstriyel bitkilerin ve yem bitkilerinin hasat dağılımı Ton cinsinden verilmektedir. Tahıllardan 212.988 ton ile en yüksek ürün alındığı görülmektedir. Yağlı tohumların ise 5.923 ton ile en az ürün alındığı izlenmektedir. En yüksek tonaj tahılda olup sırasıyla endüstriyel bitkilerin, yumru bitkilerin, baklagillerin, yem bitkilerinin ve yağlı tohumların hasat edildiği görülmektedir.



Şekil 3: 2021 TÜİK verilerine göre Elazığ da yetiştirilen bitkilerin biyokütle enerjisi dağılımı (TEP)

Şekil 3'de Elazığ ilinde bitkisel biyokütle potansiyeli olan, tahılların, baklagillerin, yumru bitkilerin, yağlı tohumların, endüstriyel bitkilerin ve yem bitkilerinin enerji değerleri TEP cinsinden verilmektedir. 85.195,2

TEP ile tahıllar en yüksek enerji değerine sahiptir. 82.505,6 TEP enerji değeri ile endüstriyel bitkiler, tahılları çok yakından takip etmektedir. En düşük enerji değeri 2.369,2 TEP ile yağlı tohumlardadır. Tahıllar başı çekse de endüstriyel bitkiler neredeyse tahıllar kadar yüksek enerji değerine sahiptir. Daha sonra enerji değerlerini sırasıyla yumru bitkiler, baklagiller, yem bitkileri ve yağlı tohumların takip ettiği görülmektedir.

Tablo 1: TÜİK'den alınan 2021 yılına ait Elazığ verileri ile bitkisel biyokütle potansiyeli

	Tahıllar	Baklagiller	Yumru bitkiler	Yağlı tohumlar	Endüstriyel bitkiler	Yem bitkileri
Ekilen alan (Dekar)	933.240	73.960	14.820	250.840	62.010	25.290
Üretim (Ton)	212.988	12.051	21.772	5.923	206.264	11.813
kcal	$8{,}51952.10^{11}$	$4{,}8204.10^{10}$	$8{,}7088.10^{10}$	$2{,}3692.10^{10}$	$8{,}25056.10^{11}$	$4{,}7252.10^{10}$
TEP	85.195,2	4.820,4	8.708,8	2.369,2	82.505,6	4.725,2

Toplam ekili alan dekar	Toplam üretim ton	Toplam TEP	Toplam enerji değeri kWh - MWh
1.360.160	470.811	188.324,4	$0{,}2.10^{10}$ - $0{,}2.10^{7}$

Tablo 1'de Elazığ ilinde bitkisel biyokütle potansiyeli olan, tahılların, baklagillerin, yumru bitkilerin, yağlı tohumların, endüstriyel bitkilerin ve yem bitkilerinin ayrı ayrı ekili alanları (dekar), toplam ekim alanı, ayrı ayrı hasatları (ton), toplam hasatları, ayrı ayrı TEP cinsinden enerji değeri, toplam enerji değeri sunulmaktadır.

Tablo 1'de görüldüğü üzere toplam ekili alan 1.360.160 dekar, toplam üretim 470.811 ton, toplam enerji değeri 188.324,4 TEP' dir. Elazığ ilinin toplam bitkisel biyokütle potansiyeli $0{,}2.10^{7}$ MWh'dir. Şehrin toplam bitkisel biyokütle potansiyelinin dikkate değer olduğu görülmektedir.

Sonuç

Ülkemizdeki artan nüfusun, gelişen sanayinin ve teknolojinin etkisiyle enerji talebindeki artış her geçen gün artmaktadır. Öte yandan fosil yakıt kaynaklarının tükenişi ve çevreye verdikleri zararlar nedeniyle yenilenebilir enerji kaynakları ön plana çıkmaktadır.

Gelişmekte olan bir ülke olan Türkiye, enerjisinin büyük kısmını dışarıdan temin ederken ilerlemesi oldukça zor olacaktır. Üç tarafının denizlerle çevrili olması, güneşli gün sayısının fazlalığı vs. dikkate alındığında Türkiye yenilenebilir enerji kaynakları bakımından oldukça zengindir. Özelikle bir tarım ülkesi olması bakımından çokça tarım atığına sahiptir. Yani büyük oranda bitkisel biyokütle potansiyeli mevcuttur. Bu potansiyelin tespiti ve değerlendirmesi Türkiye için büyük önem taşımaktadır.

Bu çalışmada, Elazığ ilinin 2021 yılına ait bitkisel biyokütle potansiyeli araştırılmıştır. Elazığ ilinin bitkisel biyokütle hesabını yapabilmek için bitkiler; tahıllar, baklagiller, yumru bitkiler, yağlı tohumlar, yem bitkileri ve endüstriyel bitkiler olarak kategorize edilmiştir. Her bir kategori kendi içinde hesaplanarak üretilen bitkinin enerji değeri tespit edilmiştir. Daha sonra ilin toplam üretimi ve toplam enerji değeri hesaplanmıştır.

Elazığ ilinin bitkisel biyokütle ekim alanı toplamda 1.360.160 dekardır. Toplam üretimi 470.811 ton'dur. Elazığ ilinin en yüksek bitkisel biyokütle enerji değeri 85.195,2 TEP değeri ile tahıllardadır. Bu sıralamayı endüstriyel bitkiler, yumru bitkiler, baklagiller, yem bitkileri ve yağlı tohumlar sırayla izlemektedir. Elazığ ilinin toplamda bitkisel biyokütle potansiyeli ise 0,2.107 MWh'dır. Türkiye için Elazığ ilinin bitkisel biyokütle potansiyelinin dikkate değer olduğu görülmektedir.

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MODELING COMBUSTION OF BIOMASS TEA WASTE IN A VERTICAL FURNACE UNDER DIFFERENT EXCESS AIR RATIOS: A CFD ANALYSIS

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ABSTRACT

This study presents the numerical analysis of biomass tea waste (BTW) combustion in a vertical furnace under various excess air ratios, using Computational Fluid Dynamics (CFD). The biomass tea waste fuel was injected at the bottom of the furnace. The primary and secondary air inlets in different cross-section areas were also located at the bottom of the furnace in which the coaxial of the injected fuel. The fuel was defined by employing the proximate and ultimate analyses. The numerical studies were carried out for four excess air ratios (1.2 to 2.1 with 0.3 increment) to determine its effect on the combustion temperature and NOx formation. The combustion simulation is based on the Species Transport model with Eddy-Dissipation turbulence-chemistry interaction model approach. The RNG k-ε model and discrete phase model (DPM) to predict the follow motion, P1radiation model for flame radiation, and NOx models were employed in the current study. Results show that the increase in excess air ratio leads to an increase in the peak temperature value in the flame zones while it decreases the furnace outlet temperature due to its cooling effect inside the furnace. The NOx formation rises with the increasing excess air ratio, and its concentration reaches 250 ppm at the furnace outlet.

Keywords: Biomass, tea waste, combustion, CFD, NOx emission

INTRODUCTION

Incineration processes are used in many areas of industry, from the food industry to thermal power plants. Coal, which is a fossil fuel, is mostly in the foreground as fuel in combustion plants. However, the use of coal causes acid gas emissions such as NOx and SOx and greenhouse gas emissions due to its intense carbon content [1]. A remarkable method to eliminate these disadvantages arising from the use of coal is to use alternative fuels. At this point, biomass resources draw attention. Biomass is obtained from various sources, such as domestic, industrial, animal wastes, and plants. It is one of the clean energy types due to being organic. For this reason, when used in biomass combustion systems, it does not pollute the environment and helps protect the environment [2]. In the literature, the effects of using biomass sources such as wood pellets, chips, wood logs, forest biomass, olive peel, wheat straw, olive seed, and pine sawdust in combustion systems have been investigated [3-5].

However, using biomass in the combustion process also has some harm. For example, biomass resources can also be associated with pollutant emissions due to their carbon and nitrogen content. Emissions emitted from burning biomass are generally grouped as incomplete combustion products or unburned species such as CO, CxHy, complete combustion emissions such as CO_2, H_2O, NOx, and bottom ash and fly ash. This situation varies depending on the biomass type, formation form, content, and properties. Some other negative effects can be listed as follows: high ash content and problems with removing ash from the reactor (sewage sludge), agglomeration, corrosion, sedimentation problems (straw) due to low ash melting temperature and high alkali content, high NOx emission level due to high nitrogen content [6-8].

The investigation of biomass fuelled combustion systems is of great importance to cope with these problems. Chen et al. [9] stated that precipitation and corrosion are easy to form in the biomass fuelled boiler, and this affects the safe and efficient operation of the boiler. Therefore, the design and operating conditions of biomass combustion systems can be improved in terms of high efficiency, low emissions, and high flexibility by using

simulations in numerical approaches [10]. Silva et al. [11] used a CFD model to burn volatile gases released from the burning of biomass on a grill. The obtained results are useful for analyzing and optimizing the combustion process and reducing pollutant emissions. It is stated that carbon monoxide and carbon dioxide emissions inside the furnace were reasonably estimated. Accordingly, they concluded that CFD calculations are an effective method for optimizing biomass combustion in a furnace. Similarly, Shiehnejadhesar et al. [12] developed a CFD-based optimization method by linking optimization routines with a gas phase CFD model for biomass combustion in a pilot-scale grate furnace. It was stated that the CFD based optimization works efficiently in terms of design optimization. Kantová et al. [13] studied four types of modifications to the flue gas duct designed to reduce pollutants in biomass combustion and reduce the amount of particulate matter in the atmosphere. The designed model consists of two parts: the combustion chamber and the flue gas channel. The study aims to optimize the flue gas path and suggest improvements in its structure. The results showed that the use of baffles had a significant effect on the reduction of particles larger than 100 µm in diameter. Milicevic et al. [14] used CFD code and machine learning models when modeling biomass combustion. They used pulverized fine straw, pinewood and switch grass as fuel. According to the findings, it has been determined that the residence time of the pulverized fuel in the reactor generally tends to decrease as the particle shape increases. As a result of the study, various predictions were given comparatively.

The combustion development of different biomass fuels under different operating conditions is decisive in designing a combustion chamber and predicting emission characteristics. Yang et al. [15] used a three-dimensional CFD model to investigate the hydrodynamic and combustion characteristics of biomass particles in an industrial-scale circulating fluidized bed furnace. CO and NOx emission formation were examined, as well as the analysis of the thermochemical process occurring during biomass combustion. One of the conclusions is that drying and pyrolysis of biomass particles mainly occur in the dense particle region. Volatile gas and coal particles continue to oxidize in the zone of diluted particles. This explains why the mid-height region of the furnace, in which most of the volatile gas is burned, has the highest temperature. Khurram et al. [16] argued that the use of biomass in coal-fired power plants provides high efficiency and fuel diversity. They examined the effect of operating parameters on NOx emissions during the burning of coal with wheat straw. The findings showed that NOx emissions decreased by increasing the wheat straw ratio in the fuel mixture. As a result, it has been suggested that wheat straw can be used as a renewable energy source for heat and energy production as well as for reducing NOx emissions. Elorf and Sarh [17] examined the combustion dynamics of pulverized olive cake in a vertical oven at different excess air ratios (1.3, 1.7, 2.3, and 2.7). According to their findings, increasing the amount of excess air diluted the CO and CO_2 emissions in the furnace, which in turn, decreased the temperature at the furnace exit, and reduced the visible flame lengths. Elorf et al. [18] conducted another study in which they investigated the effect of inlet swirl number on the flow behaviour and combustion dynamics of olive cake pulverized in a 3D vertical oven. The common conclusion of the studies is that CFD can be used as a powerful tool to predict the properties of fuels and solid biomass during combustion. Gomez et al. [19] simulated biomass combustion in a particle drop-fed fixed bed boiler by considering the gas phase and solid phase in a CFD model. The simulation model enables the understanding of heat transfer inside the boiler and emission formations.

Literature survey shows that the combustion processes of biomass fuels have been modeled using CFD and various parameters have been examined. However, the performed studies are still limited in evaluating the combustion and emission characteristics. In the current study, a CFD based biomass combustion model in a vertical furnace was simulated for tea waste, not available in the literature. The goal of the study is to determine the combustion temperature, NOx, and CO formation of biomass tea waste under different excess air ratios.

MATERIALS AND METHODS

The study was performed to investigate the combustion and emission characteristics of biomass tea waste (BTW) in a vertical furnace under different excess air ratios. The proximate and ultimate compositions for the considered tea waste are presented in Table 1.

Table 1. Proximate, ultimate compositions and heating value of BTW [20]

Proximate analysis	**(wt%, db)**
Moisture Content (Wet basis)	4.00
Volatile Matter	72.24
Ash Content	3.79
Fixed Carbon	23.97
Ultimate analysis	**(wt%, db)**
C	52.93
H	6.21
N	4.28
S	0.18
O	32.61
H:C	1.40
O:C	0.46
Higher Heating Value (MJ/kg)	20.26

The stoichiometric air-fuel ratio (*SAFR*) was calculated by combustion using the following equation BTW [21].

$$CH_aO_bN_cS_d + \left(1 + \frac{a}{4} + c + d - \frac{b}{2}\right)(O_2 + 3.76N_2) = CO_2 + \frac{a}{2}H_2O + 3.76 \times XN_2 + cNO_2 + dSO_2$$

(1)

$$SAFR = \frac{\left(1+\frac{a}{4}+c+d-\frac{b}{2}\right)\times 28.97}{12+a+16\times b+14\times c+32\times d} \quad (2)$$

where, a, b, c, d molecule numbers were estimated from ultimate analysis.

Geometric model and mesh structure

The combustion zone was created by considering a vertical furnace of which the biomass and air inlets entrance at the bottom. The air inlets are divided into two regions, primary and secondary air inlets having different cross-sectional areas. To create the computational domain, hexahedral-type meshes were generated with adequately fine mesh for fuel and air flow regions, where probable strain flows occur. Conversely, the mesh sizes from these regions to the wall were coarser due to the considered Standard Wall Function approach in the study for the near-wall modeling. Standard Wall Function in near-wall modeling requires $30 < y^+ < 300$ for the fidelity of numerical solution variables in the near-wall regions [22]. In the current study, the values of y^+ were provided in the range of 36 to 138. Thus, the simulations were carried out with the computational domain having 82,512 cells. The geometric model and network structure of the furnace can be seen in Figure 1.

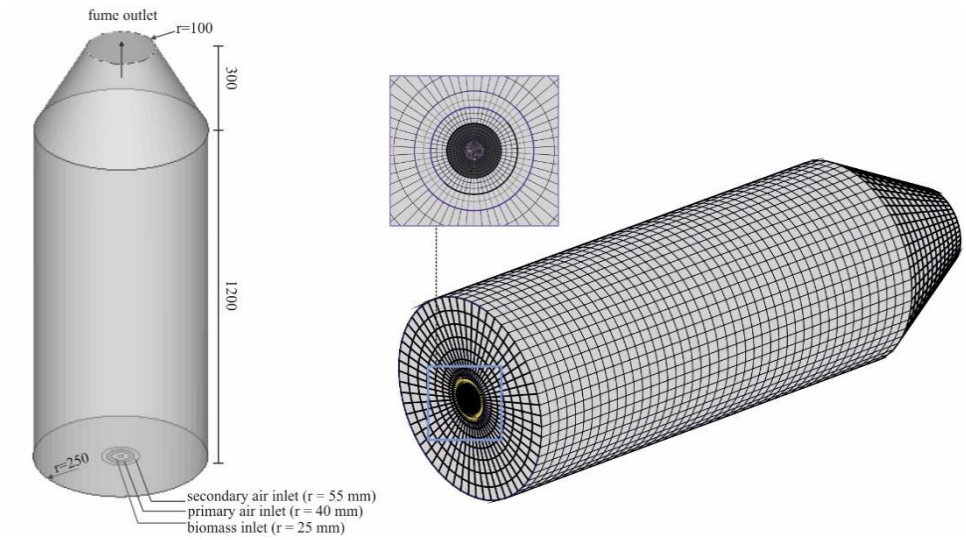

Figure 1. The geometric model of the furnace and its mesh structure

Model formulations

The model was solved by considering gas phase transport in a steady state flow regime. The continuity, momentum and energy transport equations are given in below [23],

Continuity Equation:

$$\nabla(\rho\vec{v}) = 0 \tag{3}$$

Momentum Equation:

$$\nabla(\vec{v}\vec{v}) = -\nabla p + \nabla.(\tau) + \rho\vec{g} + \vec{F} \tag{4}$$

where, p, τ are the static pressure and stress tensor, respectively. $\rho\vec{g}$ is the gravitational force and $\vec{F}$ denotes the external body forces.

Energy Equation:

$$\frac{\partial}{\partial t}(\rho E) + \nabla\cdot[\vec{u}(\rho E + p)] = \nabla\cdot\left[k_{eff}\nabla T - \sum h_j\vec{J}_j + \left(\tau_{eff}\cdot\vec{\vartheta}\right)\right] + S_h \tag{5}$$

where k_{eff} is defined as the effective conductivity, $\vec{J}_j$ is the diffusion flux of species j, E is total energy, h is sensible enthalpy, S_h is source of energy due the combustion reaction.

As the model includes reactive flow, the species conservation equation needs to be solved as follows.

$$\nabla.(\rho\vec{v}Y_i) = -\nabla.\vec{J}_i + R_i \tag{6}$$

where R_i is the net production rate of species *i* by chemical reaction, $\vec{J}_i$ is the diffusion flux of species i, which arises due to concentration gradients.

With these equations, the sub-model equations of the k-ε Turbulence model, and the P1-Radiation model were solved to attain adequate accuracy results. Additionally, the Discrete Phase Model was used for modeling biomass particles injected from the fuel inlet zone with a continuous phase approach. The particle distribution was regarded as Rosin-Rammler distribution scheme and Turbulence dispersion was modeled with Discrete Random Walk Model. Species Transport with the Eddy-Dissipation turbulence-chemistry interaction model was used for the reaction. To obtain NOx emission, NOx formation pathways, thermal-NOx, prompt-NOx, and fuel NOx model formulations [22, 24] were employed.

To solve these model equations, the finite volume method was used employing Fluent CFD simulation software, with Pressure based solver. Simple algorithm scheme was used for pressure-velocity coupling. Besides, Second-order upwind scheme was employed for the spatial discretization of the equations. In that

way, the equations were solved with the convergence criteria of 10^{-6} for the energy and P1-radiation model and 10^{-4} for others.

The simulations were carried out for four excess air ratios with an inlet temperature of 315 K under adiabatic wall conditions. The air inlet mass flow rates (m_a) were calculated by employing *SAFR* as follows;

$$\dot{m}_a = \dot{m}_f x SAFR x \lambda \quad (7)$$

where m_f is the mass flow rate of the fuel. The mass flow rates were determined by considering a 50 kW inlet power from the fuel. Table 2 presents the simulation parameters.

Table 2. The simulation parameters of BTW combustion

λ	$\dot{m}_f$ [gs^{-1}]	$\dot{m}_a$ [gs^{-1}]	$\dot{m}_{a,primary}$ [gs^{-1}]	$\dot{m}_{a,secondary}$ [gs^{-1}]
1.2	2.496	17.848	11.601	6.247
1.5	2.496	22.311	14.502	7.809
1.8	2.496	26.773	17.402	9.370
2.1	2.496	31.235	20.303	10.932

Verification of the Study

The main geometric dimensions, diameter, and length of the furnace were based on those in the reference [17], which presents the biomass olive cake combustion simulation. However, the fuel inlet positions and air inlet flow regime are different from the current study since Elorf and Sarh designed the fuel inlet on the sides of the furnace and exposed swirl flow in the air inlet and they use the PDF/mixture model for the reactions. Therefore, the occurring maximum temperature values of biomass olive cake combustion were compared to those of the reference. In the current model, the maximum temperature was obtained as 1698 K while 1600 K in the reference [17]. The difference in the temperature value is reasonable due to the differences mentioned above in the model. Thus, the current model was considered as reliable.

RESULTS

Figure 2 shows the temperature distributions along the furnace axis for all cases. When considering the flame zones, the length of the flame slightly decreases from the lowest λ value to the highest λ value as the same trend in the reference [25]. The peak temperature values in the flame zones occurred corresponding to between 0.4 and 0.6 m of the axial distance of the furnace. The increasing air mass flow rate brought about the increasing flame peak temperature values [17]. Thus, the peak temperature values were obtained as 1743 K to 1791 for excess air ratios of 1.2 and 2.1, respectively. On the other side, comparing the temperature values outer of the flame zones, the values of temperature distribution decrease when the excess air ratio increases. This is attributed to the cooling effect of excess air. Therefore, the temperature of the furnace outlet got lower with the increase of excess air ratios as shown in Figure 3.

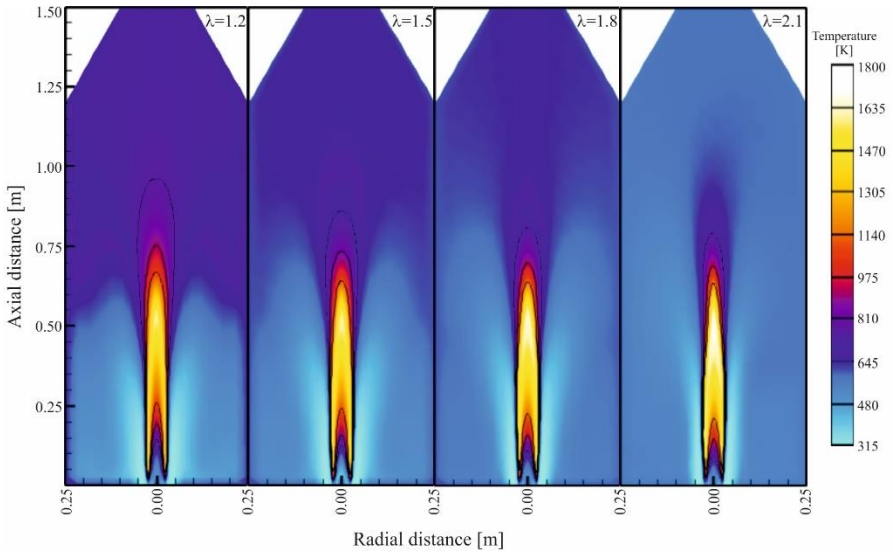

Figure 2. Temperature distribution at different λ values

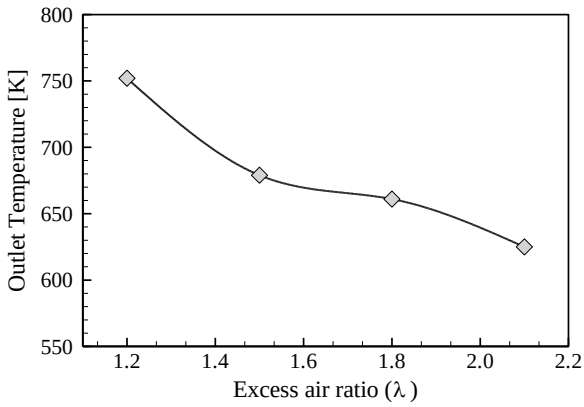

Figure 3. The variation of the outlet temperature values with λ values

Figure 4 illustrates the velocity distribution in the furnace, it can be seen that increasing the air mass flow rates leads to an increase in the velocity values, as expected. Particularly, the temperature gradient corresponding to flame zones increases with the increase of λ values. This can imply that flame stabilization deteriorates with the increase in λ values. It can be also attributed to why the flame length got lower because the increasing velocity with the increase in excess air ratio dragged the flame.

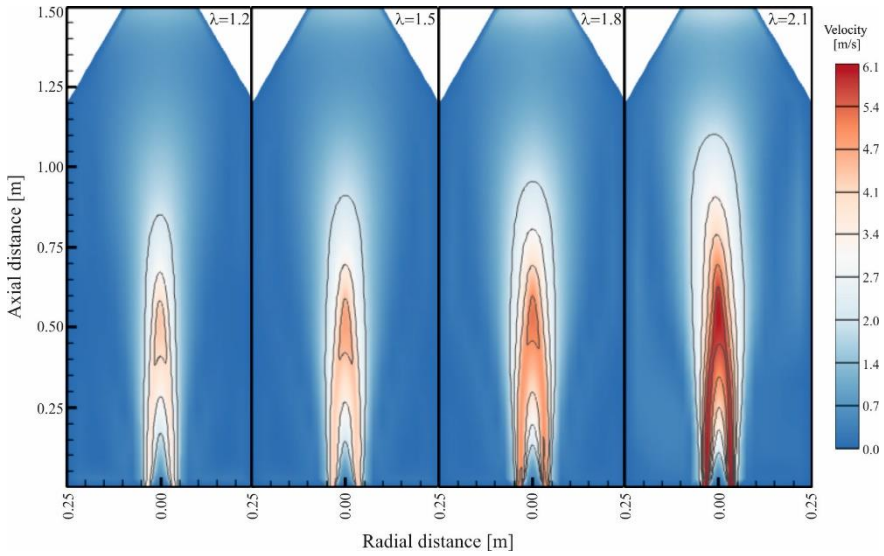

Figure 4. Velocity distribution at different λ values

NOx emission consists of nitric oxide (NO), nitrogen dioxide (NO_2), and nitrous oxide (N_2O). However, the most of compound in NOx is NO. The NOx formation commonly occurs in three pathways due to high temperature (thermal NO), short residence time in rich mixture zones (prompt NOx), and content of N in fuel (fuel NOx formation).

The thermal NO formation is based on Zeldovich mechanisms, which are dominant above 1800 K [22, 26]. The prompt-NO formation is regarding to high-rate reaction in which N_2 reacts with hydrocarbon radicals resulting in intermediate species. Thus, the reaction of the intermediate species with O_2 leads to the formation of NO. Thus, the prompt-NO formation rate is high in the rich-mixture zone at low and moderate temperature levels [25].

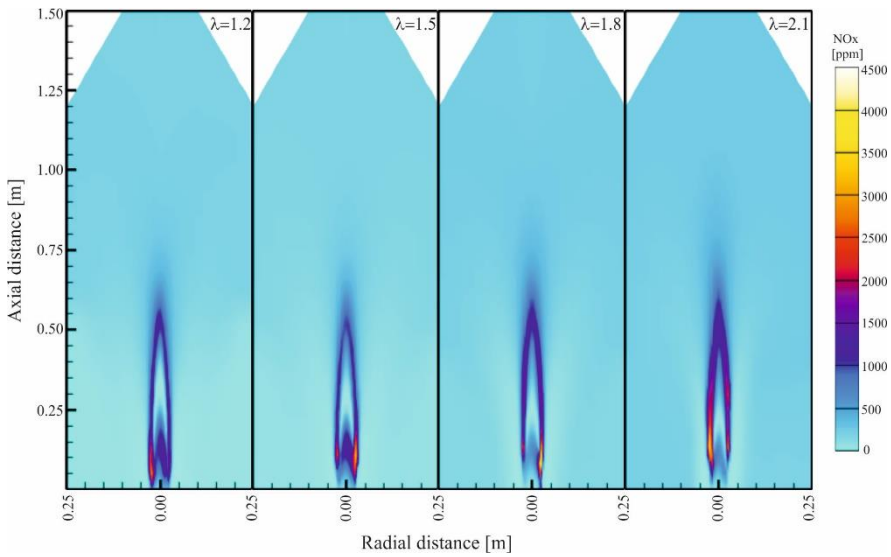

Figure 5. NOx formation at different λ values

Fuel NO formation depends inherently on the N content in a fuel. Figure 5 shows the NOx formation in the furnace for all cases. As the maximum temperature zone is lower than 1800 K in the furnace, the contribution of thermal NO to the total NOx formation is quite low. Therefore, the NOx formation zones are near the boundary of the flame zones, not in the highest temperature zones. As shown in the figure, the increase of λ

gave rise to extending the high level NOx formation zones. The reason for this stems from increasing N_2 and a high velocity causing the short residence time (see Figure 3) with the increase of λ.

The concentrations of NOx from the furnace outlet are given in Figure 6. As shown in the figure, the increasing excess air ratio leads to a rise in the NOx concentrations. The NOx at a λ value of 1.2 is 192 ppm while 250 ppm at a λ value of 2.1.

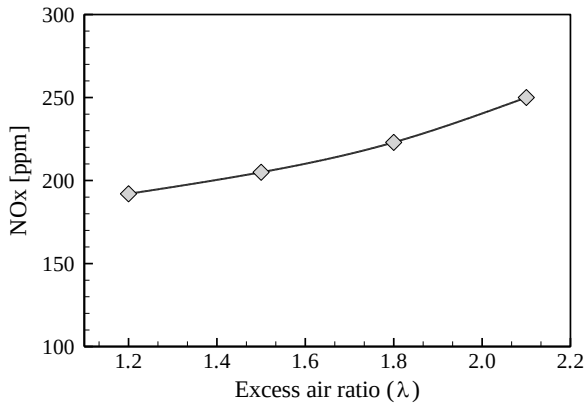

Figure 6. NOx emissions at the furnace outlet versus λ values

CO formation is related to temperature and O_2 concentration in a combustion reaction zone. The lack of O_2 and/or insufficient temperature level brings about a decrease in the oxidation of CO to CO_2. Therefore, the formation of CO can be expected in rich-mixture zones and low temperature zones. Figure 7 shows the CO formations in the furnace. It can be seen that the CO formations in the reaction zones take place in the rich mixture region in which the direction of the axis of the biomass fuel is injected. Another zone is nearly corresponding to the flame boundary, in which temperature is the lowest in the reaction zone (see Figure 2). When λ value increases, CO formation decreases in the zones due to the increasing O_2 concentration [27].

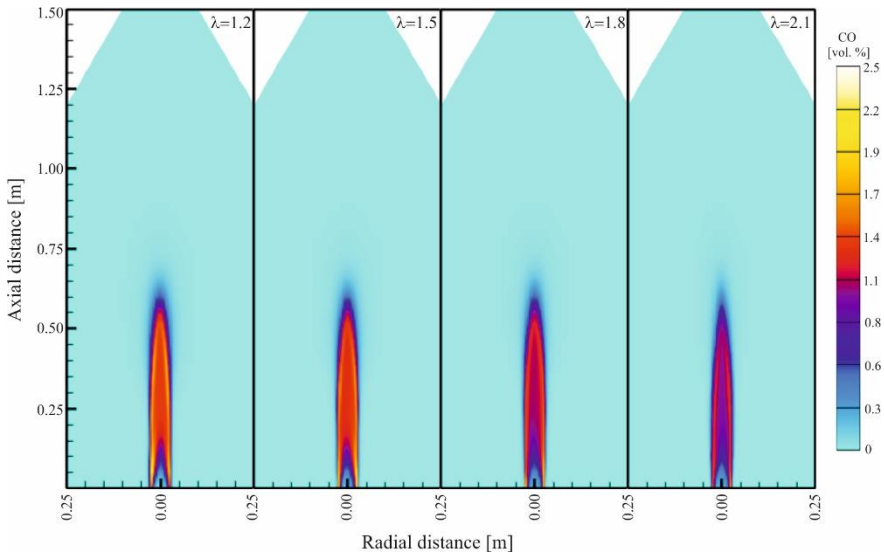

Figure 7. CO formation at different λ values

CONCLUSION

In the current study, biomass tea waste combustion was modeled in a vertical furnace by using computational fluid dynamics, based on the finite volume method. The simulation was performed for various excess air ratios of 1.2 to 2.1 with 0.3 increments to reveal the effects of the excess air ratio on combustion temperature and

NOx and CO formation and their concentration at the furnace outlet. The numerical approach was verified by comparing the peak temperature occurring inside the furnace.

Based on the results, the main conclusions can be stated as follows:

- The increase in excess air ratio caused to increase in the peak flame temperature while it decreases in the furnace outlet temperature as it cools the furnace interior zones except for the flame zone. The peak temperature values are 1743 K to 1791 for excess air ratios of 1.2 and 2.1, respectively. The increase in excess air ratio leads also to a slight decrease in the flame length due to increasing velocity.
- NOx formation in the reactive zones resulted from prompt-NO and fuel-NO formation pathways rather than the thermal-NO formation pathway model which is dominant above the temperature of 1800 K. Therefore, the increasing excess air ratio gave rise to increasing the NOx formations. Besides, the maximum NOx concentration at the furnace outlet was obtained as 250 ppm for an excess air ratio of 2.1.
- CO formation decreases with the increase in the excess air ratio. CO formation occurred in the rich mixture zone and flame boundary region. The maximum CO formation in concentration reached 2.2% by volume.

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SOLVOTERMAL YÖNTEMLE KARBON KUANTUM NOKTALARININ SENTEZİ VE DİMETİLAMİN BORANDAKİ HİDROLİZİNDEN HİDROJEN ÜRETİMİ

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ÖZET

Son zamanlarda artan enerji ihtiyacının artması ve çevre dostu olacak enerji kaynaklarına talepten dolayı; hidrojen enerjisi ile ilgili yapılan araştırmalar hızla artmaktadır. Bunun yanı sıra borhidrürlerden elde edilecek olan katalizörlerin aktivitesinin, tekrar kullanılabilirliğinin ve sentezleme yöntemide önemlidir. Bu bağlamda bu çalışmada, biyobazlı üreden karbon kuantum noktaları elde edip üzerine Ni(0) metalini doplayarak Ni@CQD nanokatalizörünü sentezledik. Bilindiği üzere biyokütle bazlı nanokatalizörler hem çevre dostu, hem de üretiminin kolay olması bakımından önemlidir. Ayrıca çalışmamızda ayrıca ilk defa solvotermal sentez yöntemi kullanılarak şekil ve boyut kontrollü Ni bazlı katalizör sentezlenmiştir. Bilindiği üzere solvotermal sentez yönteminde su yerine farklı organik çözücüler kullanılarak malzemenin sentezi yapılmaktadır. Burada öncelikle üreden solvotermal yöntemle karbon kuantum noktaları (KKN) elde edildi. Daha sonra, Ni metali elde edilen (KKN) üzerine farklı yükleme koşulları ile en etkili yükleme metodu belirlendi. Çalışmanın bir sonraki aşamasında ise, hidrojen üretiminde stabiliteyi sağlamak amacıyla optimum sodyum hidroksit konsantrasyonu belirlendi. Burada farklı sodyum hidroksit konsantrasyonunun dimetilamin boranın hidrolizi (DMAB) ile hidrojen üretimi üzerinde ne kadar etkin ve önemli olduğu belirlenmiştir.

Anahtar Kelimeler: Karbon Kuantum Noktaları, Ni katalizör, Hidrojen, Dimetil aminboran

Giriş

Son zamanlarda fosil yakıtların artan tüketiminin sonucu olarak artan küresel ısınma ve çevre sorunlarından dolayı yeni ve çevreci enerji kaynaklarına bir yönelim olmuştur. Bu temiz enerji kaynaklarının başında ise hidrojen (H_2) enerjisi gelmektedir[1-3]. Hidrojen, fosil yakıtların yerine kullanılmak üzere çevreci olduğundan dolayı, geleceğin yakıtı olarak kabul edilir ve sadece yakıt hücrelerinde kullanıldığında bir ürün olarak su üretir. Bu nedenle, yüksek bir enerji yoğunluğuna sahiptir. Kısaca hidrojen, yakıt hücresinde yakılırken sıfır emisyon üretir, bu da aralıksız yenilenebilir enerji kaynaklarından farklı olarak sürdürülebilir ve temiz bir enerji taşıyıcısı olarak son derece çekici bir enerji aracıdır. Hidrojen; üretimi, depolanması taşınması ve kullanımı olmak üzere 4 aşaması bulunmaktadır[4]. Bunların arasında (H_2) enerjisinin güvenli olarak taşıma ve depolama sorunu bulunmaktadır. Ancak bu iki sorununun üstesinden gelecek olan, depolama ve taşıma problemlerini ortadan kaldıran borhidrürler öne çıkmaktadır. Bu bağlamda, hidrojen depolama malzemeleri olarak kullanılan boron tabanlı malzemeler (sodyum borhidrit, amonyum boran, lityum borhidrit, potasyum borhidrit, metilamin boran vb.) yüksek gravimetrik hidrojen kapasiteleri ve uygun hidrojen salınım kinetiği nedeniyle potansiyel adaylar çekmiştir.

Bu Bor bazlı malzemeler arasında, amonyak boranın en basit metil türevleri olan dimetilamin boranın $(CH3)_2NHBH_3$) , (DMAB) literatürde kapsamlı bir şekilde çalışılmamıştır. Bununla birlikte, oldukça yüksek bir gravimetrik hidrojen içeriğine sahiptir (ağırlıkça %16,9)[4, 5]. Hidrojen açısından zengin DMAB 'nin hidroliz taşınabilir hidrojen depolama uygulamaları için en uygun yol gibi görünmektedir. Ortam koşulları altında uygun bir katalizörün varlığında DMAB molü başına 3 mol H2 açığa çıkarabilir. Bu bakımdan

MeAB'nin taşınabilir, pratik uygulamaları için verimli ve kararlı katalizörlerin geliştirilmesi büyük önem taşımaktadır. Şu ana kadar Ru [6], Pd-Co[7], Pt/C[8], RoFe[9], Rh [10] gibi birçok soy ile çalışmalar heterojen yada homojen metal nano katalizörü ile çalışılmış olup tamamen yeşil sentezle karbon kuantum noktalarının üzerine geçiş metali olan Ni doplanarak elde edilen ucuz ve kullanışlı bir katalizör olan Ni@KKN ile çalışmalar yapılmamıştır. Dimetil amin boranın hidroliz tepkimesi oda şartlarında Ni@KKN nanokatalizörü varlığında aşağıdaki gibi olup reaksiyon sonunda 3 mol hidrojen gazı açığa çıkmaktadır.

$$H_3N{\cdot}BH_3 + 2H2O \xrightarrow[\text{Oda şartları}]{Ni@KKN} [(CH_3)_2NH_2][BO_2]+3\ H_2 \qquad (1)$$

Sentezlenen metal nanopartiküllerin katalitik performansı, genellikle destek malzemesine metallerin homojen olarak dağılımından dolayı, yüzey alanının artmasıyla ilişkilendirilebilir. Bu nedenle katalizörler sentezlenirken topaklaşma olmaması için genellikle son zamanlarda; MOF, Al2O3, CNT, GO, CQD gibi katı destek malzemeleri kullanılmıştır. Destek malzemelerin kullanılmasıyla hem metallerin eşit dağılımı meydana gelir, hem de aktif bölgeler ortaya çıkarak, katalizörlerin katalitik performanslarının artmasına sebep olur.

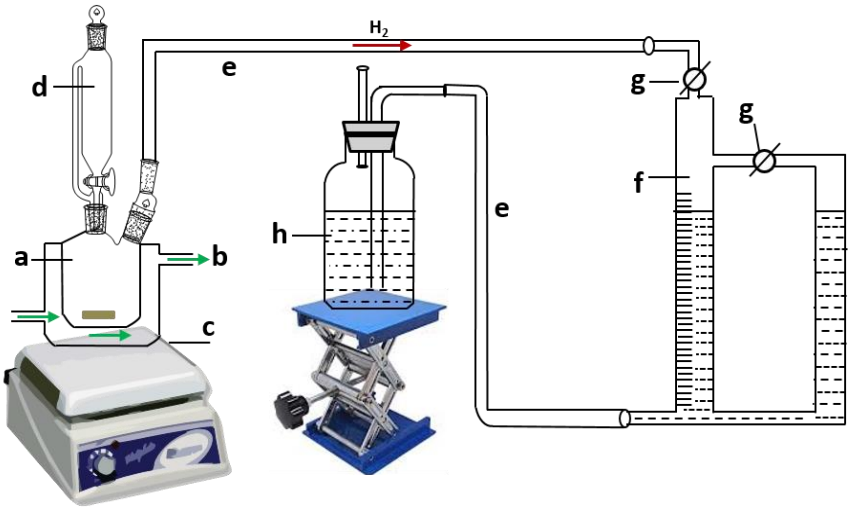
Bu çalışmada üre destek malzemesi kullanılarak 4 farklı yükleme şekli ile en iyi metal yükleme modeli belirlendi. burada ilk önce sadece Ni(0)'ın DMAB' daki hidrolizine, daha sonra üre üzerine emdirme metodu, ve iki farklı karbon kuantum yükleme şekliyle; otoklava konularak çözücü ile birlikte eklenen metal belli bir sıcaklık ve sürede elde edilen karbon kuantum noktalarının üzerine doplanan Ni metali ile, Ni@KKN nanokatalizörü elde edilerek bunların DMAB deki hidrlizlerine bakıldı. Daha sonra optimum NaOH konsantrasyonlarına bakılarak en uygun NaOH konsantrasyonu belirlendi.

Materyal ve Yöntem

Bu çalışma karbon kuantum nokta destekli nikel (Ni) atomlarından oluşan mono atomik, destekli katalizörün hidroliz katalitik tepkimesini konu almaktadır. Çalışma kapsamında karbon kuantum noktacık kaynağı olarak üre, Ni metal atom kaynağı olarak $NiCl_2*6H_2O$ kullanılmıştır. Çalışmada öncelikle karbon kuantum nokta sentezi gerçekleştirildi. Bu işlem solvotermal yöntemle yapıldı. Solvotermal üretimde saf su yerine dimetilforamid (DMF) kullanılarak sentez ve yükleme işlemi gerçekleştirilmiştir. Yükleme işleminin tamamlanmasının ardından belli miktarda $NaBH_4$ ün oluşturduğu 20 mL çözelti varlığında indirgenme işlemi gerçekleştirilerek Ni@CQD katalizörünün sentezi sağlandı. Sentezlenen yapı vakumlu süzme ve azot atmosferinde kurutma işlemleri sonucunda ufalanarak hidroliz deneylerinde kullanılmışlardır.

Bulgular ve Tartışma

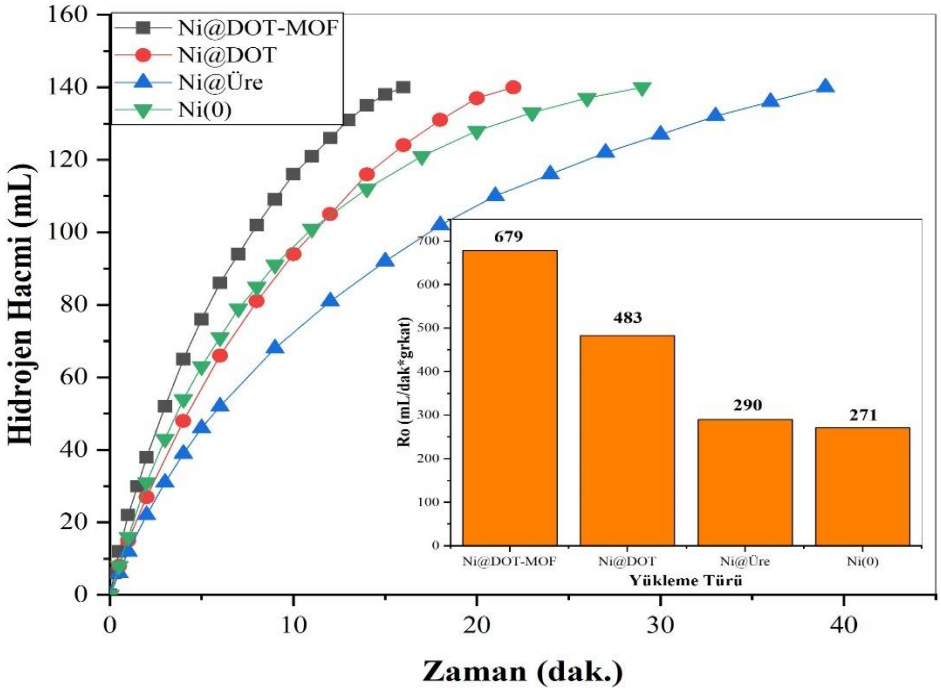
Dimetil aminboran katalizör varlığında metanolizine ilişkin deneysel çalışmalarda kullanılan sistemin açık şeması aşağıdaki şekilde verilmiştir. Sistem; bir gaz büreti, kapaklı bir erlen ve sıcaklık kontrollü bir kriyostattan meydana gelmektedir. Belirli bir miktar ve konsantrasyona sahip sodyum borhidrür çözeltisi kapaklı erlene konularak, daha önceden hazırlanmış olan katalizörler çalışma kapsamında belirlenen kütle oranlarında eklenerek hidroliz olayı gerçekleştirildi. Sentezlenen katalizörlerin zamana bağlı olarak eldilen gaz hacimleri hazırlanan su tuzağı kullanılarak hidrojen gaz büretinde toplatıldı. Burada farklı farklı katalizör miktarı, farklı $(CH_3)_2NHBH_3$' ün (DMAB) konsantrasyonları ve farklı sıcaklıklardaki etkinliklerine bakılarak hidrojen gazının hacim değerleri, belirli zamanlarda okunarak grafiksel olarak katalizörün etkinliği belirlendi. Elde edilen bu grafiklere göre tepkimelere ilişkin aktivasyon enerjisi, tepkime derecesi gibi reaksiyon kinetiğine ilişkin veriler oluşturuldu.



Şekil 1. Katalizörlerden hidrojen üretimi deney sisteminin açık şeması

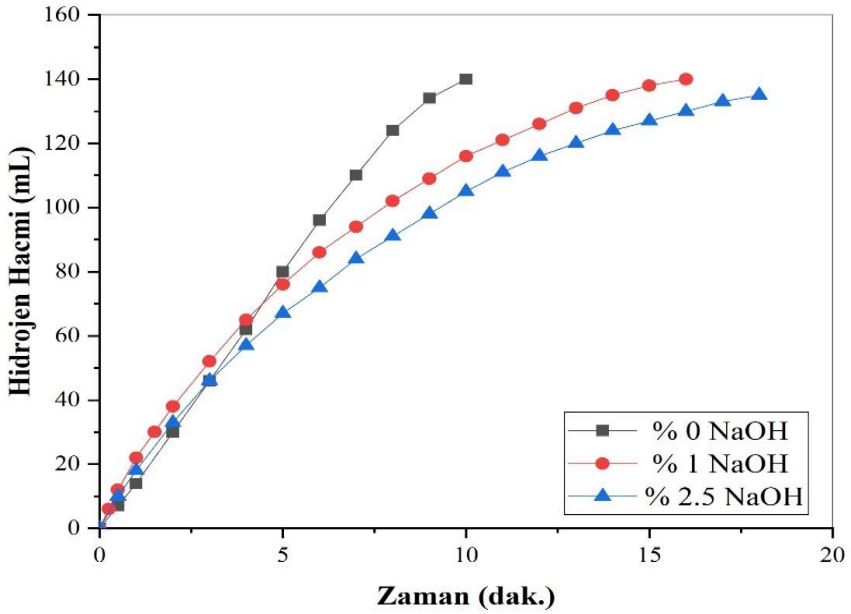
Sonuç ve Öneriler

Şekil 3, Ni katalizörü varlığında farklı yükleme modellerinin DMAB hidrolizi üzerindeki etkisini göstermektedir. Şekilden görüleceği gibi Ni (0) desteksiz olarak DMAB hidrolizindeki katalitik aktivitesinin düşük olduğu görülmekte, daha sonra ise emdirme yöntemi ile üre destekli katalizörünün ise solvotermal yöntemle elde edilen karbon kuantum noktalarına göre hidrojen üretim hızının daha az olduğu görülmektedir. Burada solvotermal yöntemle elde edilen Ni@KKN nanokatalizörün aktivitesinin yüksek olmasının temel sebebi elde edilen karbon kuantum noktalarının çok küçük boyutta olmaları ve Ni metalinin destek malzemesi üzerinde homojen dağılımından dolayı, katalitik aktivitesinin artmasına sebep oldu.



Şekil 2: Farklı Metal Oranları (25 mg Katalizör, %0 NaOH, 30 C Sıcaklık, 0,25 gr $NaBH_4$).

Bilindiği üzere borhidrürler genellikle kendiliğinden bozunmaktadır. Bunun için borhdidrür çözeltilerinin pH'ı arttıllarak kararlı ortalama pH 9 olması gerekir. hale getirilir. Daha sonra uygun katalizörler varlığında kontrollü bir şekilde hidrojen üretimi için gerekli koşullar sağlanır. Bu bağlamda biz 3 farklı NaOH konsantrasyonun DMAB'ın hidrojen üretimi üzerinde etkisine bakıldı. Şekilden görüldüğü gibi; NaOH konsantrasyonu arttıkça hidroliz süresinin artığı görülmektedir. Bunun asıl sebebi, DMAB'ın pH değerinin 20°C de 9 civarında olması yani bazik değerde olması hidroliz süresini artırmakta ve hidrojen üretim hızınının azaldığı görülmektedir.



Şekil 3. Hidrojen hacminin NaOH konsantrasyonuna etkisi (%0 NaOH, 25 C Sıcaklık, 2mmol DMAB, CQD destekli)

Teşekkür ve Bilgilendirme Notu

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HYDROLYSIS AND KINETIC MECHANISM OF DIMETHYLAMINE BORANE USING NI NANOCATALYST OBTAINED VIA GREEN SYNTHESIS

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ABSTRACT

In this study, an environmentally friendly, practical, economical, and effective Ni catalyst was synthesized using a green synthesis method. The obtained Ni catalyst's impact on the hydrolysis of dimethylamine borane (DMAB) was investigated. DMAB was found to have a relatively high hydrogen storage capacity (16.9%), making it a promising candidate for hydrogen storage. In this research, carbon quantum dots obtained from urea using the solvothermal method were doped with Ni metal to obtain Ni(0) nano catalyst, and its effect on DMAB hydrolysis was examined. To determine the kinetic mechanism of Ni(0) nanocatalyst, DMAB hydrolysis was carried out at different temperatures, and the activation energy, reaction order, and enthalpy were determined. It was found that the reaction follows zeroth-order kinetics, with an activation energy of 50.8 kJ/mol and an enthalpy of 48.2 kJ/mol.

Keywords: Green Synthesis, Ni@KKN nano catalyst, Hydrogen, Dimethylamine borane

Introduction

Although there may sometimes be conflicts between countries due to the increasing need for energy in the last 30 years, considering the damage caused by fossil fuels to the environment, studies on clean energy have accelerated. hydrogen (H_2) energy stands out among these clean energies[1, 2]. Currently, one of the primary challenges in hydrogen technologies is the secure and effective storage. The demand for high-capacity storage materials is steadily growing[3, 4]. Due to its extremely low density, the liquefaction and compression of hydrogen gas pose significant challenges for its transportation under normal conditions. Over the last ten years, there has been increasing focus on the metal-catalyzed dehydrogenation of sodium borohydride ($NaBH_4$)[5], ammonia-borane (NH_3BH_3)[6] and its related compounds, such as and $(Me)_2NHBH_3$[6, 7]. In addition, the catalytic dehydrogenation of amine-borane adducts has played a significant role in polymer synthesis , as well as in conjunctions dehydrogenation-hydrogenation, and transfer hydrogenation, contributing significantly to advancements in this field. The boron and nitrogen compounds stand out because to their tunable temperature and pressure features, which make them distinct from hydride and porous materials in terms of hydrogen release and uptake[7, 8]. DMAB exhibits exceptional water solubility at ambient temperature.

DMAB exhibits exceptional water solubility at ambient temperature. In this context, the hydrolysis of DMAB can be easily realized in the presence of suitable catalysts. The catalytic performance of synthesized metal nanoparticles can generally be attributed to the increase in surface area due to the homogeneous distribution of metals on the support material. For this reason, solid support materials such as MOF[9], Al2O3[6], CNT, GO[10], CQD[11] have recently been used to avoid agglomeration when synthesizing catalysts. With the use of support materials, both the even distribution of metals occurs and the active sites appear, leading to an increase in the catalytic performance of the catalysts. DMAB hydrolysis takes place at room temperature in the presence of suitable catalysts as shown in reaction (1) below.

$$H_3N{\cdot}BH_3 + 2H_2O \xrightarrow[RT]{Ni@KKN} [(CH_3)_2NH_2][BO_2]+3\,H_2 \qquad (1)$$

In this study, for the first time, the activity of Ni@KKN nanocatalyst obtained by doping Ni into carbon quantum dots obtained from urea using solvothermal method (as solvent, dimethyl formamide) on DMAB was investigated. Here, after first determining the loading conditions; DMAB hydrolysis at different temperatures was carried out in the presence of Ni@KKN nanocatalyst and the degree of activation of the catalyst was calculated.

Material And Method

This study deals with the hydrolysis catalytic reaction of a mono-atomic, supported catalyst consisting of carbon-quantum-point supported nickel (Ni) atoms. In the study, urine was used as a source of carbon quantum point, and Ni-metal-atom $NiCl_2*6H_2O$ as the source. The study primarily carried out carbon quantum point synthesis. This operation was carried out by solvothermal method. Synthesis and loading processes were carried out using dimethylforamide (DMF) instead of pure water in solvothermal production. After completion of the loading process, the Ni@CQD catalyst was synthesized in the presence of a 20 mL solution that produced a certain amount of $NaBH_4$. The synthesized structures were used in hydrolysis experiments, which resulted in vacuum floating and nitrogen-drying processes.

Findings and Discussion

The open scheme of the system used in the experimental studies of methanolysis in the presence of dimethyl aminboran catalysts is given as follows. The system consists of a gas cluster, a covered loose, and a temperature-controlled cryostat. The hydrolysis process was carried out by applying a solution of sodium borohydrate with a certain amount and concentration and adding the previously prepared catalysts to the mass ratios specified in the study. The volumes of the synthetic catalysts were collected in the hydrogen gas batch using a water trap that was prepared depending on the time. Here, the catalyst's effectiveness was graphically determined by looking at different quantities of catalyst, different concentrations of $(CH3)_2NHBH_3$ (DMAB) and its activity at different temperatures, by reading the volume values of the hydrogen gas at specific times. Based on these graphs, data on reaction kinetics such as activation energy and degree of reaction were generated.

dimethylamine borane

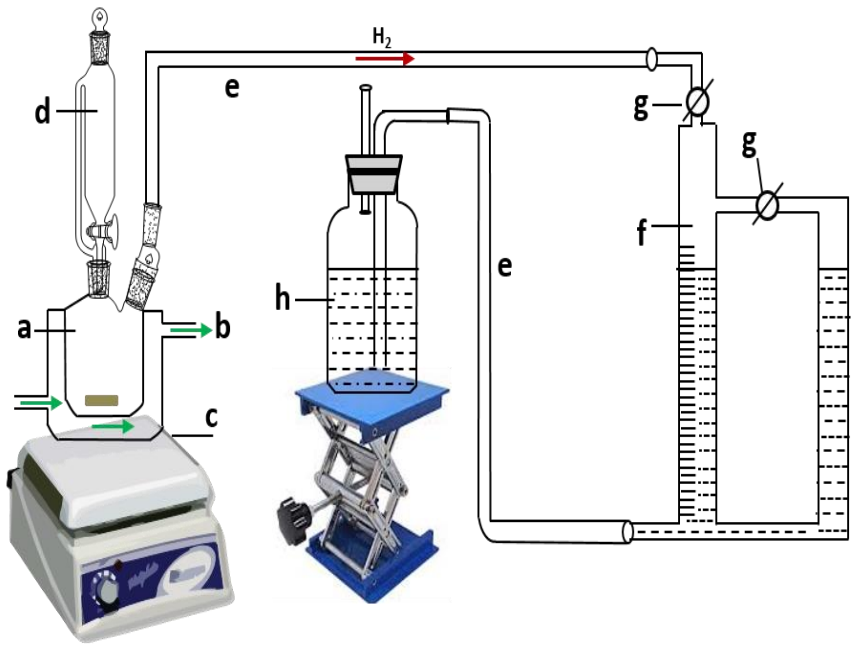

Figure 1. Open diagram of the experimental system for hydrogen production from catalysts

Conclusion and Recommendations

The hydrolysis of DMAB in the presence of Ni@KKN nanocatalysts at different temperatures is shown in Figure 2. The gas volume/time graph shows that the catalytic hydrolysis reaction rate increases in proportion to the temperature. As seen in the picture, the increase in temperature reduces the hydrolysis time and increases the speed of hydrogen production.

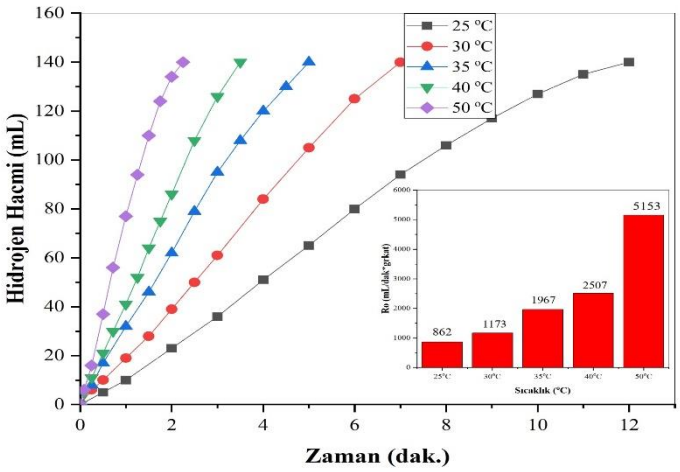

Figure 2: Different Temperature Rates (%0 NaOH, 25 °C Temperature, 2mmol DMAB,)

Catalytic hydrolysis reactions were carried out at different temperatures in the presence of Ni@KKN nanocatalysts to determine the effect of temperature on the hydrolyse reaction of DMAB and to determine degree of reaction along with the activation energy, which are important thermodynamic parameters of the reaction. In Figure 3, the volume of the H2 gas that is released in the hydrolysis reaction at different temperatures is determined to be 0 degrees when the curve is adjusted depending on zero (0), first (1) and degree. karşı zaman grafiği verilmektedir. Gaz hacmi/zaman grafiği katalitik hidroliz tepkime hızının sıcaklıkla doğru orantılı olarak arttığını göstermektedir.

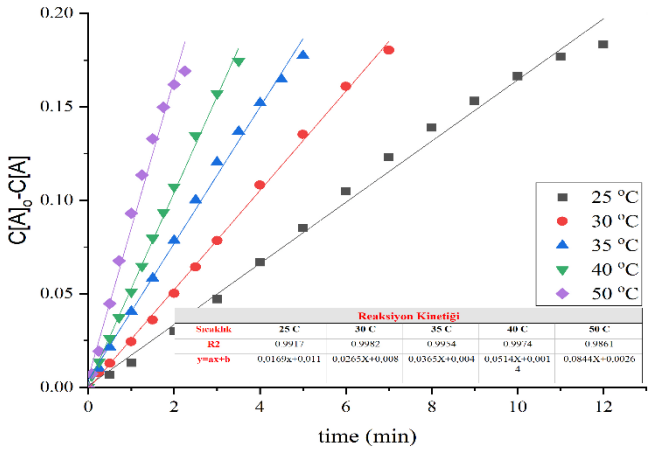

Figure 3: Determination of the reaction degree of the Ni@CQD catalyst (%0 NaOH, 25 °C Temperature, 2mmol DMAB, CQD supported)

Arhenius equations were used to calculate the activation energy of the reaction. The change in reaction speeds is converted into curves (Arhenius) with the help of these equations, and the activation energy is calculated at 50.86 kJ/mol, given in Figure 4.

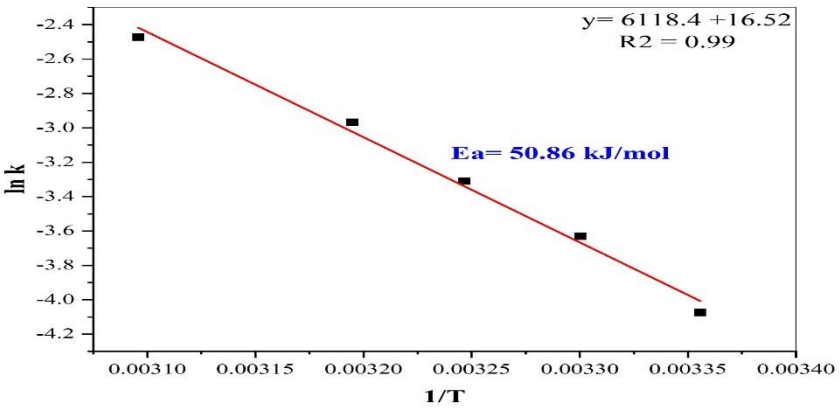

Figure 4: Ea value of the Ni@CQD catalyst (%0 NaOH, 25 C Temperature, 2mmol DMAB)

Thanks and Information Note

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DESIGN AND FABRICATION OF A TEST STATION FOR VARIOUS FUEL CELLS

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ABSTRACT

The fact that most of the world's energy needs are met by fossil fuels and the reserves of these resources are insufficient have led humanity to search for sustainable, alternative, and cleaner energy sources. One of the alternative electrical energy generation technologies is fuel cells that use hydrogen as the main fuel. Fuel cells directly convert the chemical energy of the fuel into electrical energy and have features such as high efficiency and low negative environmental impact.

In this paper, a study is presented on the development of a test station designed for use in solid oxide fuel cell (SOFC) development and research that can test more than one fuel cell type. Since different types of fuel cells operate at different operating temperatures, humidity values, gas pressure, and physical pressure forces, it is important that these parameters can be changed and measured at the same time. In line with this perspective and especially taking into account the needs of researchers and users in this regard, the necessary technical needs and features were determined. In addition, existing products have examined, and the advantages and differences of the prototype developed within the scope of this study were revealed. Apart from the basic features for a test station, the features required for a test station include working at different temperatures, a cabin with precise temperature control and cooling features, load pressure stabilization, heat recovery features, the integration of sensitive pressure sensors for leakage testing, etc. By making the necessary changes and improvements in the test station according to the determined technical needs, a prototype was obtained that can measure fuel cell single cells or stacks with a maximum power of 100 W. In addition, the FC 50 model proton exchange membrane (PEM) type fuel cell was tested at this test station.

Keywords: Fuel cells, SOFC, PEMFC, test system design, alternative energy.

Introduction

Fuel cells are clean, environmentally friendly, and highly efficient energy conversion technologies. Electrical energy is produced only by chemical reactions without the use of a steam boiler or turbine. Fuel cells, which are obtained by the electrochemical reaction between hydrogen and oxygen and whose total efficiency can reach up to 80%, are also known as continuously operating batteries or electrochemical machines. Fuel cells have advantages such as small size, modularity, fuel flexibility, and quiet operation. Fuel cell systems are classified as follows according to the type of electrolyte they use: alkaline fuel cell (AFC), polymer exchange membrane fuel cell (PEMFC), molten carbonate fuel cell (MCFC), phosphoric acid fuel cell (PAFC), and solid oxide fuel cell (SOFC) (Kaya et al., 2018, Larminie & Dicks, 2003).

In order to investigate the efficiency and durability of fuel cells, the operation of a fuel cell must be examined with appropriate techniques. For this reason, fuel cell test stations are designed and manufactured. The expected features for these test stations are to be able to make multiple measurements, be equipped with versatile control systems, record measurement results, etc (Eikani et al., 2012, Marignetti et al., 2009).

In a test study conducted using a Ballard trademark fuel cell and a specially designed fuel cell test station, the effect of air flow rate and pressure, which can be controlled using gas flow control, a pressure regulator, and a pressure sensor, on the performance of the battery was examined. As a result, it has been observed that the airflow rate affects the results more when pure hydrogen is fed to the fuel cell, while when mixed hydrogen is used, the effect of the air is limited. It has been noted that in low load situations (0.12 A/cm^2), the effect of air

pressure and flow rate is limited, while in higher load situations, high flow rate and air with increased pressure have a positive effect on power (Marignetti et al., 2009). In another study, a fuel cell test station was developed, and a PEM fuel cell of 25 cm^2 was tested. The power supply, temperature and flow control equipment, valve, and pressure controller were used in the test station. It was aimed to determine the best operating conditions for the PEM fuel cell in the tests carried out by changing the relative humidity, pressure, temperature, and flow rate values at the test station. The humidifier was directly connected to the flow line, and a system with thermostat was obtained based on the method of passing gas through water. As a result of the study, a value of 2.9 mW/cm^2 was obtained for the PEM fuel cell. It has been stated that the humidifier needs to be improved by adding water level control (Barbouche et al., 2013). In another study, the development of reversible SOFC, which can work as both an electrolyzer and a fuel cell, has been mentioned. The work involves integrating an automatically controlled steam transmitter into the already existing reversible SOFC system. For this, a step motor-controlled valve was added, and the Arduino circuit was used for valve position control. A pressure transmitter has been added to monitor water vapor pressure. A mechanism for valve control has been designed and added to the system. It states that fuel cell test could not be carried out on the test station due to pandemic conditions (Ayati, 2020).

In this study, it is aimed to design a fuel cell test system in which all variables and parameters can be monitored and controlled. In this way, it is aimed to repeat the development tests under the same conditions and to monitor the effect of changes made in the fuel cell membrane or stack design on performance. In light of these goals, many technical devices, such as sensitive pressure sensors, valves, and temperature monitoring sensors, have been integrated into the anode inlets and outlets. The most important development was the technical development that allowed different fuel cells to be tested at the same test station. A test station has been created that can provide solutions for many fuel cell types, including fuel cells operating at very different temperatures, such as PEMFC and SOFC.

Test Station Design

The fuel cell testing station is designed to measure fuel cell single cell or stack with a maximum power of 100 W. Reactant feeds are designed to be connected to a pressure tube, an air pump, and a fuel processor outlet. As seen in Figure 1, adjustable valves were used in the pre-fuel cell inlet system to start and stop the flow and also to adjust the flow rate. In addition, flowmeters (Alicat-Whisper and Sierra-SmartTrac100) are available to measure the flow rate of the fluid passing through it. Sensors are available to measure the temperatures of the entering fluids, as well as pressure sensors (Pakkens-DL 10) to see the total line pressure and calculate the total pressure loss. There are even control valves to prevent the fluids from flowing reversely in the event of a pressure imbalance. In addition, a pressure regulator (SMC-ITV) has been used to ensure that the system responds to rapid pressure changes and to achieve repeatability. Heat exchangers are present to ensure that the temperatures of the gases advancing to enter the fuel cell are at the operating temperature of the fuel cell. Temperature measuring sensors (Elimko-PT100) are connected to monitor the efficiency of the heat exchanger. There is a pressure sensor to measure the blockage and pressure vessel in the heat exchanger, the last system element before the battery.

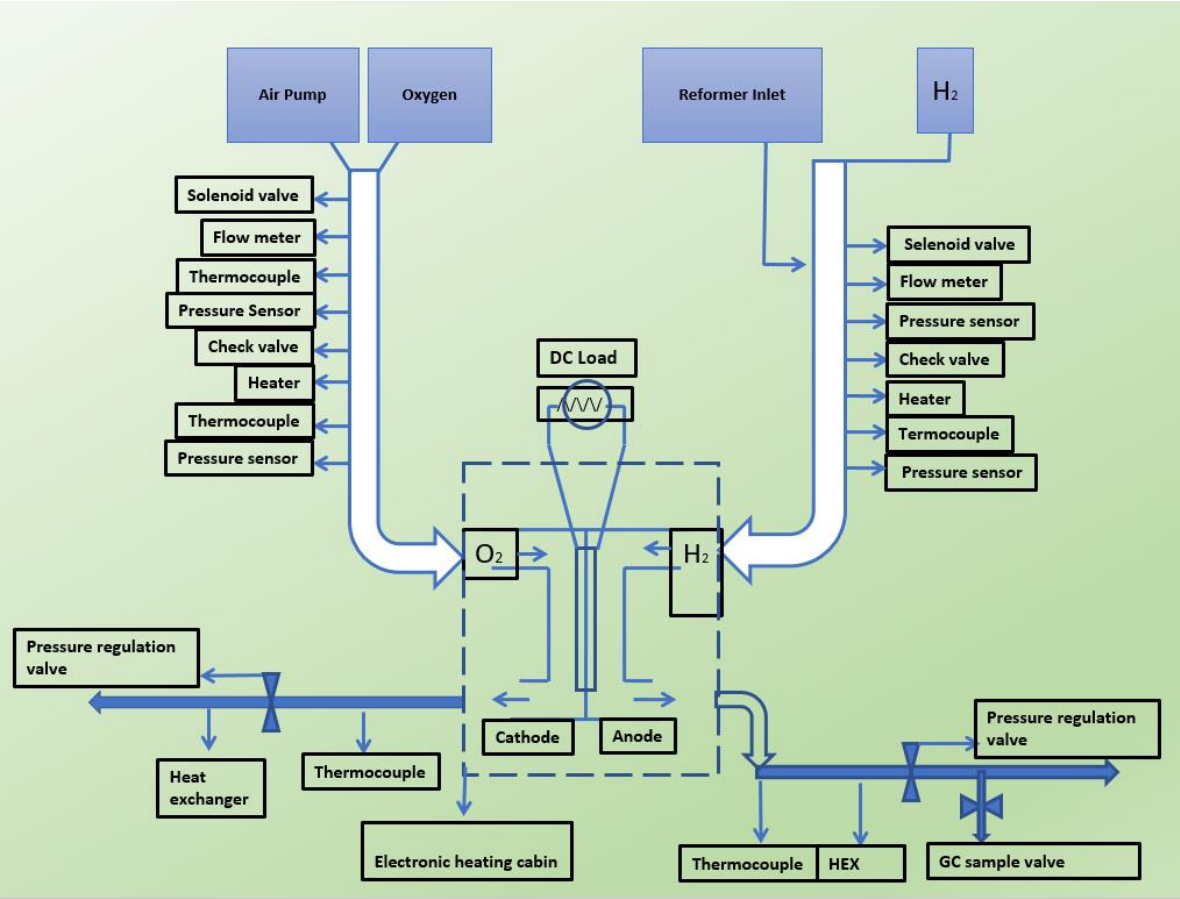

Figure 1. Flow chart of the designed fuel cell test station

When the fluids entered the fuel cell, the electrochemical energy resulting from the reaction has been transferred to the outside as electrical energy via nickel plates. It is possible to make electrical measurements by making a direct DC load connection with suitable stack. The cabinet in which the fuel cell is located has been designed and manufactured precisely to provide the ambient temperature at the operating temperature appropriate for the type of fuel cell placed inside. This cabin is specially reinforced with extra profile support and fire brick on the bottom base to withstand load and pressure. In addition, an actuator (Timotion-TA2P-2K) has been added to the cabin ceiling for use in fuel cells that require pressing force to ensure sealing.

In the fuel cell test station, as seen in Figure 2, there is an air pump, flowmeter, sensors, heat exchanger, and pipe connections at the bottom of the body. In the upper part of the body, there is a high-temperature furnace and insulation materials. On the other side of the furnace compartment, there are management units such as the furnace temperature controller, DC load unit (Bk Precision-8601), touch control panel, and electronic panel.

Figure 2. Left-front-right side photos of the fuel cell test station from left to right

Findings and Discussion

To perform the functional tests of the fuel cell test station developed for solid oxide fuel cell tests, an experimental set containing the PEM fuel cell produced by the Heliocentris company, shown in Figure 3, was used. The names of the equipment in Figure 3 are also given in Table 1. The PEMFC module in the experimental set was first operated on the experimental set to which it was connected, and measurements were made. It is then tested at the fuel cell test station, which is capable of testing various types of fuel cells developed within the scope of this study.

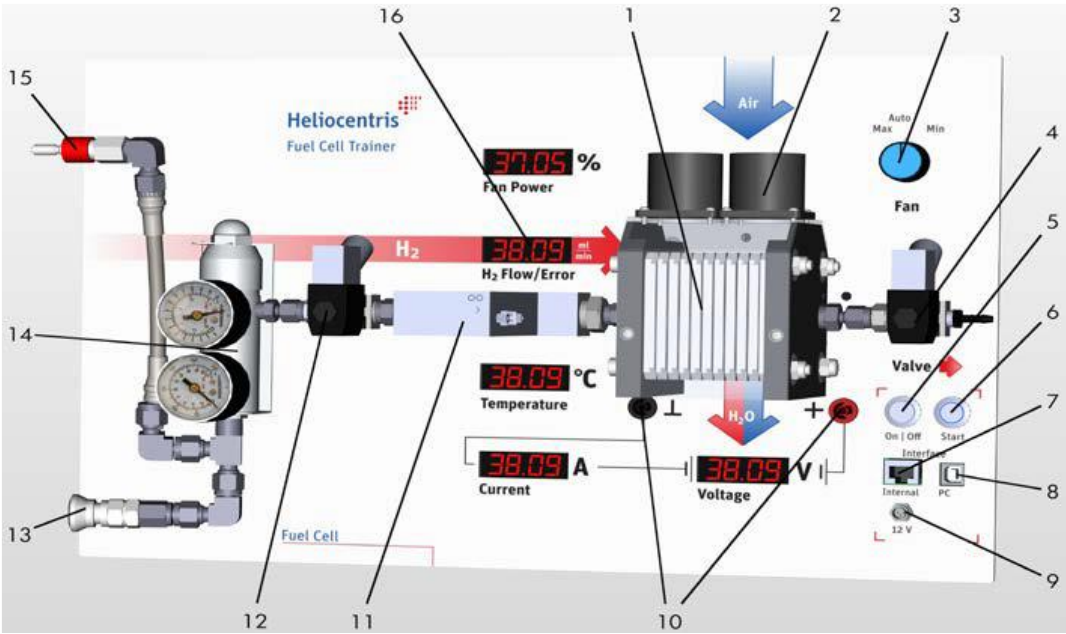

Figure 3. Heliocentris PEM experiment set (Heliocentris, 2013)

Table 1. Heliocentris experiment set elements according to Figure 3 (Heliocentris, 2013)

No	Equipment Name	No	Equipment Name
1	PEM fuel cell	9	12V power input
2	Fan	10	Power output
3	Fan adjustment knob	11	Hydrogen flowmeter
4	Outlet valve	12	Solenoid valve
5	On/Off button	13	External H_2 connection input
6	Start button	14	Pressure regulator
7	RJ 45 socket	15	Metal hydride connection
8	USB connection socket	16	H_2 flow amount indicator

The technical specifications of the FC 50 model PEM fuel cell stack given in the catalog are given in Table 2. This table states that the PEM fuel cell can produce a maximum power of 50 W and that the open circuit voltage will be 9 V when the fuel cell reaches hydrogen saturation and is not under load (Heliocentris, 2013).

Table 2. PEM fuel cell stack technical specifications (Heliocentris, 2013)

Property	Value
Designed power output	40 W
Maximum power output	50 W
Open circuit voltage	9 V
Designed current output	8 A
Designed voltage lower value	5 V
Maximum current value	10 A
Minimum voltage value	4 V
Hydrogen consumption at designed power	580 Nml/min
Maximum operating temperature	50 °C

In the on-site trials, the performance test of the PEM fuel cell has been carried out as seen in Figure 4. Basic flow control is provided by using a flow control flowmeter in the experimental set. A speed-adjustable air fan was used for air flow. While the fan speed is displayed as a percentage on the system, the real-time hydrogen flow amount can be seen on the flowmeter. In Table 3, the power value obtained as a result of the experiment did not exceed 5 W. In this case, it has been observed that the maximum measurable power of the PEM fuel cell is approximately 1/10 of its nominal power. This result is interpreted as a decrease in the performance of the PEM fuel cell stack due to the current system not working for a long time, etc.

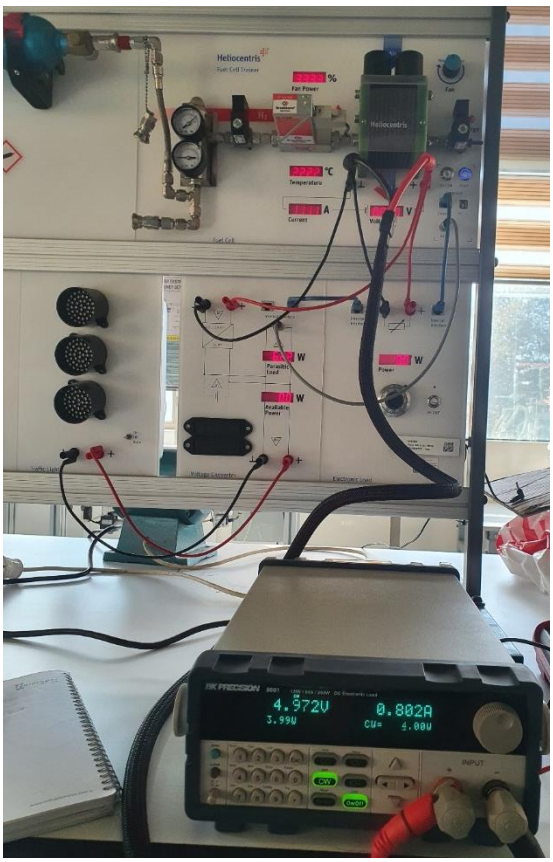

Figure 4. PEM fuel cell performance test photo on the experimental set

Table 3. PEM fuel cell performance test results

Open Circuit Voltage (V)	Hydrogen Flow Rate (ml/min.)	Set Current (A)	Voltage Under Load (V)	Power (W)
5.71	116	0.8	4.97	4
5.71	221	1	4.55	4.55
5.71	320	1.2	4.12	4.94

The PEM fuel cell is connected to the test station presented in this study, and tests are carried out at different flow rates and load values. At the beginning of the test, after making the necessary connections, the pressure value in the pressure regulator was set to 300 mbar. The power connection of the DC electronic load unit is made, and it is first operated in open circuit mode. In the next step, the high-pressure hydrogen tube is opened from its main valve, and the mechanical pressure regulator on the tube is brought to 1 bar. A flow rate of 1 l/min is entered into the anode flow meter, and then the electronic valve is opened from the test station control interface. While waiting for the pipelines filled with air to be swept with hydrogen, the open-circuit voltage of the PEM fuel cell began to be monitored. The air fan used to deliver the oxidant is also activated, and the necessary conditions are prepared for the operation of the PEM fuel cell. During the test, an attempt is made to ensure fuel saturation of the PEM fuel cell by gradually increasing the hydrogen flow rate to 1-2-3-4 l/min. In the tests, fuel cell open circuit voltage, load current, voltage under load, and power values are measured and recorded. Figure 5 and Figure 6 show the V-I and P-I graphs of the fuel cell tested using these measured values, respectively. Measurement areas made at four different hydrogen flow rates are shown as 1, 2, 3, and 4 on the graphics.

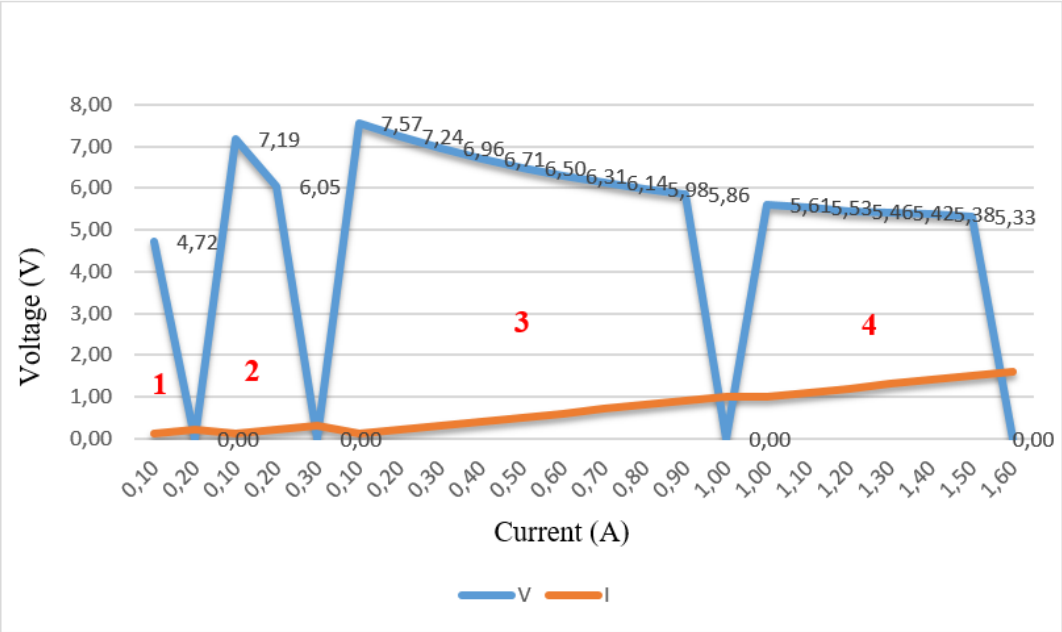

Figure 5. V-I graph of the tested PEM fuel cell under different flow rates

Examining Figures 5 and 6 together, it can be seen that if hydrogen is supplied at 1 liter per minute, the open circuit voltage cannot reach 5 V; therefore, no power can be obtained when a load of 0.1 A is applied. By increasing the hydrogen flow rate to 2 l/min, power under load began to be obtained. As shown in Figures 5 and 6, as a result of increasing ohmic losses and decreasing fuel concentration, points occur where the power that can be obtained is zero during each flow rate change. In other words, it is necessary to evaluate the fuel cell V-I curve separately for each flow rate region. Accordingly, it can be seen that the obtained graphs follow the fuel cell characteristic curve.

In addition, while the highest power value could be obtained from the PEM fuel cell in the Heliocentris experimental setup at 4.94 W, it could be increased by 60% to 8 W in the fuel cell test station, as seen in Figure 6. Thanks to the features offered by the fuel cell test station, such as wider flow rate adjustment, humidification of the anode gas line, heating of the furnace, etc., users are offered the opportunity to work with hundreds of different scenarios and variables.

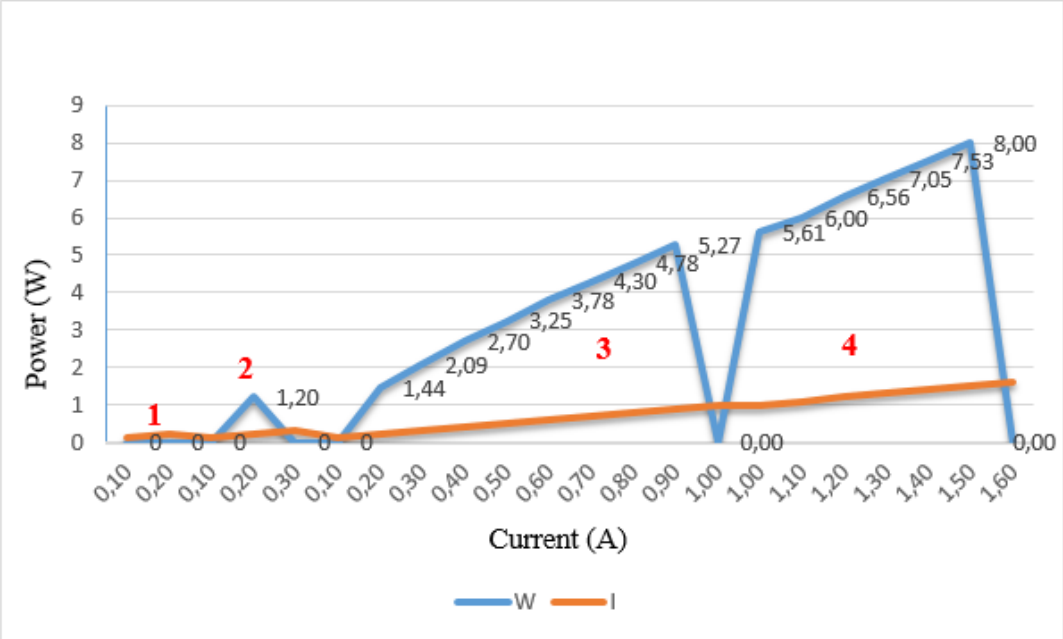

Figure 6. P-I graph of the tested PEM fuel cell under different flow rates

Conclusion

In this study, the fuel cell test station needed by researchers in fuel cell research and development studies has been moved beyond being usable only for a single type of fuel cell study and has been provided with technical features that can test various types of fuel cells. The anode humidification system required by the PEM fuel cell has been added to the test station. For this purpose, a new system has been obtained by adding a water tank, a heating system, and a unit that measures humidity and temperature and also provides control. Additionally, a PEM fuel cell is tested at the designed test station, and its performance is determined successfully. Especially thanks to the test station, it has been observed that by humidification the membrane of the fuel cell, there is an increase in performance compared to its current state.

Thanks

We would like to thank Bursa Expert Metal Company and its officials for their support and opportunities.

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POTENTIAL BENEFITS AND DRAWBACKS OF WASTE-TO-ENERGY CONVERSION: A REFLECTION ON THE ENVIRONMENTAL IMPACT, ECONOMIC VIABILITY AND SOCIAL IMPLICATIONS

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ABSTRACT

The world is facing numerous environmental challenges, including the increasing amount of waste generated. Waste management has become a critical issue, and finding sustainable solutions is imperative. One promising approach is the conversion of waste into energy, which has not only addressed the issues of waste management but also contribute to the production of clean, renewable and sustainable energy. This paper provides a detailed survey on the potential benefits and drawbacks of waste-to-energy conversion, focusing on its environmental impact, economic viability, and social implications. While improper waste disposal can result in land pollution, water, and air, causing severe harm to ecosystems and human health, it has been observed that waste conversion into energy offers a renewable and sustainable energy source. Traditional energy sources such as fossil fuels, are finite and contribute to greenhouse gas emissions, whereas, waste-to-energy technologies have the potential to generate electricity and heat. This energy can be utilized for various purposes, including powering homes, industries, and transportation systems. Waste conversion into energy can also contribute to economic growth and societal development. Therefore, it can reduce the reliance on non-renewable resources and decrease carbon emissions, thus combating climate change. In other words, findings from this survey also revealed that the conversion of waste into energy can significantly reduce the amount of waste sent to landfills and incinerators, thereby mitigating environmental pollution. Tapping into the energy potential of waste can diversify the energy mix and minimize dependence on fossil fuels. Although development and implementation of waste-to-energy projects require investments in infrastructure, technology, and skilled labour, it can stimulate economic activities and create employment opportunities in the renewable energy sector. However, one key concern is the proper management of emissions and by-products. While waste-to-energy technologies have significantly improved in recent years, there is need for stringent regulations and monitoring to ensure that emissions are within acceptable limits and any by-products are safely handled. Hence, careful planning, regulation, and monitoring are necessary to ensure the safe and efficient implementation of these technologies.

Keywords: Waste-To-Energy, Environment, Pollution, Economic viability, Waste management.

1. Evolution of Waste-to-Energy

Waste to energy (WtE) refers to the process of converting various forms of waste into usable energy, such as electricity, heat, or fuel. This technology has gained significant attention in recent years due to its potential as a sustainable solution to address both waste management and energy generation challenges. By examining the evolutional context, potential for future growth of the current state of WtE can better be understood (Kumar, et al., 2021; Nagawa, 2022; Nubi et al., 2022).

i. One of the earliest documented waste to energy facilities was established in Nottingham, England, in 1874 (Khan et al., 2022; Wilson et al., 2023). This facility utilized waste incineration to produce steam,

which was then used to power a nearby textile factory. This marked the beginning of waste incineration as a viable method for energy generation (Wang et al., 2020; Themelis, 2023)

ii. In the early 20th century, waste to energy technology witnessed further advancements with the introduction of mass incineration plants. These plants were designed to handle large quantities of waste and generate electricity on a larger scale. Notable examples include the first municipal waste incineration plant in the United States, which was built in 1905 in New York City (Makarichi, et al., 2018; Dadario et al., 2023).

iii. The 1970s and 1980s saw a significant shift in waste to energy technology, driven by increasing concerns over environmental pollution and the need for sustainable waste management solutions. This period witnessed the development of more advanced incineration technologies, such as fluidized bed incinerators and gasification systems. These technologies aimed to minimize emissions and maximize energy recovery from waste. Kalair et al., 2021; Okafor et al., 2022; Okedu et al., 2022).

iv. The 1990s marked a turning point for waste to energy technology, as the focus shifted towards more efficient and environmentally friendly processes (Mostakim et al., 2021; Rezania et al., 2023. The introduction of waste-to-energy plants with combined heat and power (CHP) systems allowed for the simultaneous production of electricity and heat, increasing overall energy efficiency (Malinauskaite et al., 2021).

In recent years, waste to energy technology has continued to evolve, incorporating advanced technologies like anaerobic digestion and pyrolysis (Aneni, 2018; Farooq et al., 2021). Anaerobic digestion involves the decomposition of organic waste in the absence of oxygen, producing biogas that can be used for energy generation. Pyrolysis, on the other hand, involves the thermal decomposition of waste materials to produce bio-oil, gas, and char. The history of waste to energy technology showcases its evolution from simple waste incineration to more advanced and efficient processes (Uche-Soria et al., 2019; Rezania et al., 2023). The development of this technology has played a crucial role in addressing waste management challenges while simultaneously generating clean and renewable energy. As waste generation continues to increase, waste to energy technology will likely play an even more significant role in the future, contributing to a more sustainable and circular economy. The 21st century has witnessed remarkable advancements in waste-to-energy conversion technologies, offering promising solutions for sustainable waste management. Anaerobic digestion, thermal conversion, and plasma gasification are among the key technological advances that have improved the efficiency, effectiveness, and environmental performance of waste-to-energy conversion processes (Clausen et al., 2019; Alao et al., 2022; Obileke et al., 2023). These technologies have the potential to reduce greenhouse gas emissions, promote resource recovery, enhance energy security, and create economic opportunities.

2. Historical Background of Waste-to-Energy Technologies

The concept of converting waste into energy dates back to ancient civilizations, where biomass was used as a primary energy source (Osman et al., 2023). For instance, the ancient Romans utilized animal waste and wood to generate heat and power for their bathhouses. However, it was not until the 19th century that waste to energy technology began to take shape in a more organized manner. This occurred during the industrial revolution when waste management became a pressing issue (Saleem et al., 2022; Manikandan et al., 2023), leading to the development of more sophisticated waste conversion technologies enumerated as follows:

i. Incineration: Incineration emerged as the first significant waste-to-energy conversion process in the late 19th century (Wenga, 2023). The introduction of controlled combustion techniques allowed for the efficient burning of waste materials, producing heat and steam. Incineration plants became popular in urban areas, addressing the growing concerns of waste accumulation and pollution. However, the environmental impacts of incineration, such as air pollution and ash disposal, raised concerns and led to the exploration of alternative technologies (Johnson and Affam, 2019).

ii. Anaerobic Digestion: In the early 20th century, anaerobic digestion gained recognition as a viable waste-to-energy conversion process. This biological process involves the decomposition of organic waste in the absence of oxygen, producing biogas (methane and carbon dioxide) and nutrient-rich digestate. Anaerobic digestion not only generates renewable energy but also provides a solution for organic waste management. The development of anaerobic digestion technologies has been driven by

advancements in microbial research and process optimization (Mata-Alvarez et al, 2000; Tshemese et al., 2023; Aworanti et al., 2023).

iii. Gasification and Pyrolysis: Gasification and pyrolysis technologies emerged in the mid-20th century as alternatives to incineration. Gasification involves the conversion of solid waste into a synthetic gas (syngas) through high-temperature reactions in the presence of limited oxygen (Shadle et al., 2022; Durak, 2023). Pyrolysis, on the other hand, involves the thermal decomposition of waste in the absence of oxygen, producing liquid or gaseous fuels. These processes offer higher energy efficiency and lower emissions compared to incineration, making them attractive options for waste conversion.

In recent years, technological advancements have further improved waste-to-energy conversion processes. Integrated systems, such as combined heat and power (CHP) plants, have been developed to maximize energy recovery from waste. Additionally, the utilization of advanced sorting and pre-treatment techniques has enhanced the efficiency of waste conversion processes. Furthermore, the integration of renewable energy sources, such as solar and wind, with waste-to-energy systems has opened up new possibilities for sustainable energy production.

3. Advancements in Waste-to-Energy Technologies

The increasing global population and rapid industrialization have led to a significant rise in waste generation. Waste management has become a critical global issue due to the increasing population and industrialization. Traditional waste disposal methods, such as landfilling and incineration, have proven to be environmentally unsustainable and pose significant challenges. However, the 21st century has witnessed remarkable advancements in waste-to-energy conversion technologies, offering promising solutions to address the growing waste crisis (Un, 2023; Kataya et al., 2023). Improper waste management poses serious environmental and health risks. However, waste-to-energy (WtE) conversion processes have emerged as a sustainable solution to address these challenges. Waste-to-energy conversion refers to the process of generating energy, such as electricity or heat, from various types of waste materials (Nubi et al., 2022). This process involves the transformation of waste into usable energy through different technologies, including incineration, anaerobic digestion, gasification, and pyrolysis. Advancements in waste-to-energy technologies are enumerated as follows:

i. Incineration: Incineration is one of the most widely used waste-to-energy conversion technologies. Recent advancements in incineration processes have focused on improving energy efficiency, reducing emissions, and enhancing waste treatment capabilities. For instance, the introduction of advanced combustion control systems and flue gas treatment technologies has significantly reduced air pollutant emissions, making incineration a cleaner and more sustainable option (Singh and Shukl, 2014; Thabit et al., 2014).

ii. Anaerobic Digestion: Anaerobic digestion is a biological process that converts organic waste into biogas and digestate. Technological advancements in anaerobic digestion have led to improved process efficiency, increased biogas production, and enhanced waste treatment capabilities. The integration of pre-treatment technologies, such as thermal hydrolysis, has shown promising results in enhancing biogas yields and reducing digestion time. Advanced anaerobic digestion systems, such as high-rate digesters and two-stage processes, have improved the efficiency and effectiveness of this technology (Yellezuome et al., 2023; Collins et al., 2023).

iii. Gasification: Gasification is a thermochemical process that converts carbonaceous materials into a synthesis gas (syngas) comprising hydrogen and carbon monoxide. (Abanades et al., 2021; Maitlo et al., 2022). Recent advancements in gasification technologies have focused on improving syngas quality, increasing energy efficiency, and reducing tar and particulate matter emissions. The integration of advanced gas cleaning systems, such as hot gas filtration and catalytic tar cracking, has significantly improved the overall performance of gasification processes.

iv. Pyrolysis: Pyrolysis involves the thermal decomposition of waste materials in the absence of oxygen, resulting in the production of bio-oil, syngas, and char. Technological advancements in pyrolysis processes have aimed at improving product yields, enhancing energy recovery, and reducing environmental impacts. The development of advanced reactor designs, such as fluidized bed and microwave-assisted pyrolysis, has shown promising results in terms of higher product yields and

improved process efficiency (Varma et al., 2018; Yaashikaa et al., 2020; Al-Rumaihi et al., 2022; Osman et al., 2023).

v. Plasma Gasification: Plasma gasification is an emerging waste-to-energy conversion technology that utilizes extremely high temperatures generated by plasma torches to convert waste into syngas. This technology offers several advantages, including the ability to handle a wide range of waste types, high energy recovery rates, and minimal emissions. Ongoing research focuses on improving the scalability and cost-effectiveness of plasma gasification systems.

These advancements offer numerous benefits, including sustainable energy generation, efficient waste management, and reduced environmental impacts. As progress is made towards a more sustainable future, further research and development in waste-to-energy conversion technologies are crucial to maximize their potential and address global waste management challenges.

4. Types of Waste-to-Energy Conversion Technologies

Waste-to-energy (WtE) conversion technologies have gained significant attention as a sustainable solution for managing waste while simultaneously generating renewable energy. Some of the common types of waste-to-energy conversion technologies are enumerated as follows:

i. Incineration: Incineration is one of the most widely used WtE conversion technologies. It involves the combustion of waste materials at high temperatures, generating heat and electricity. Proponents argue that incineration reduces the volume of waste, minimizes landfill requirements, and produces energy. However, critics raise concerns about air pollution, including the release of greenhouse gases and toxic emissions, which can have detrimental effects on human health and the environment. As shown in Figure 1, the waste is placed in an enclosed area and then mixed until it is ready to burn. The mixed waste enters the combustion chamber through a time-shifted grate, where it is rotated and exposed. Fine particles (fluids) are removed from the filter bag. Acidic flue gases are neutralized by injecting lime or sodium hydroxide. Unburned residue and "underspray" are passed through magnets and vortex separators to remove iron (iron and ferrous iron) and other metals such as copper, brass, nickel and aluminum for recycling. The remaining ash can be used as aggregates for road surfacing and rail barriers. The superheated steam powers the electric generator. The cooled steam is converted to water through the condenser or becomes a source of heat for homes and businesses. The cooled stream is heated in a superheater and superheater to complete the steam cycle. Activated carbon (carbon with oxygen to increase porosity) is injected with hot gases to extract and remove heavy metals such as mercury and cadmium. Nitrogen oxides in the rising flue gases are neutralized by the injection of ammonia or urea. Dioxins and furans are destroyed by exposing the flue gases to very high temperatures.

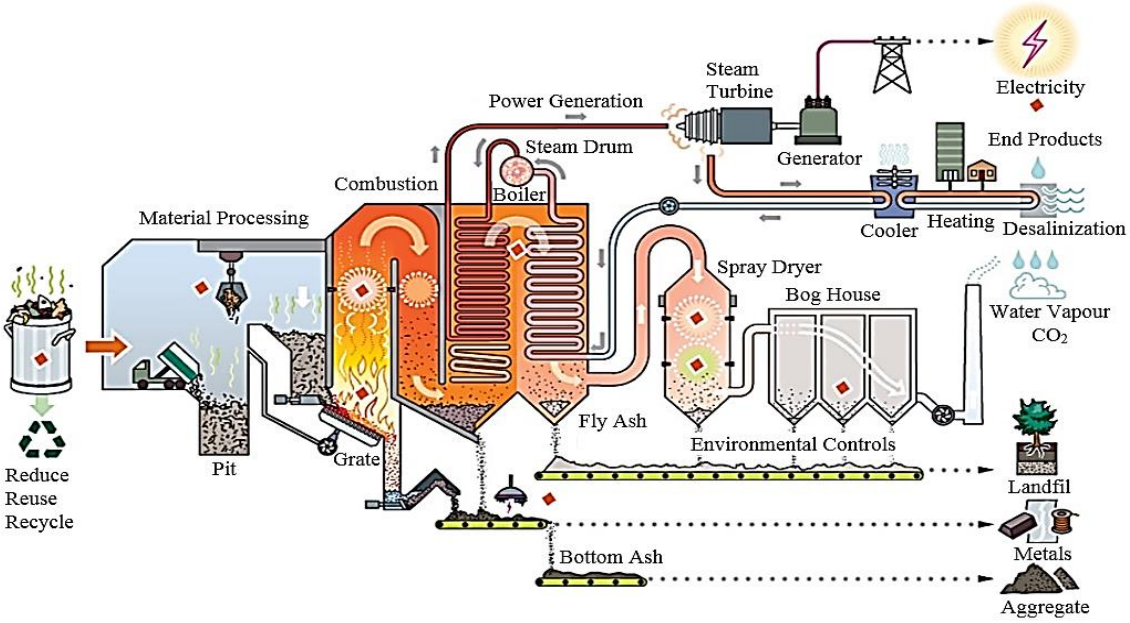

Figure 1: Incineration waste-to-energy conversion facility

ii. Anaerobic Digestion: Anaerobic digestion is a biological process that decomposes organic waste in the absence of oxygen, producing biogas and nutrient-rich digestate. As shown in Figure 2, this technology is particularly suitable for organic waste, such as food waste and agricultural residues. Advocates emphasize the potential for reducing greenhouse gas emissions, generating renewable energy, and producing valuable by-products. However, challenges related to feedstock availability, process efficiency, and digestate management need to be addressed for wider adoption. Anaerobic digestion technologies converts animal manure, municipal sewage solids, food waste, industrial wastewater and waste, fats, oils and greases (FOG) and a variety of other organic forms of waste into biogas, twenty four hours a day and seven days a week. Digested solids separated from the process are composted, used on dairy farms, employed directly to fields or converted into other viable materials. The nutrients present in the liquid stream are used as manure for agricultural applications.

Digestion begins with bacterial hydrolysis of the input material to break down alkaline polymers, such as carbohydrates, to make them available to other bacteria. Acid bacteria convert sugars and amino acids into carbon, hydrogen, ammonia and carbonic acid. Acetic acid-producing bacteria convert the resulting organic acids into acetic acid and other ammonia, hydrogen, and carbon dioxide. Finally, methanogens convert these products into methane and carbon. Anaerobic digester systems are classified as follows:

a. Complete Mix Digester: Also known as continuously agitated digesters are sealed, heated tanks equipped with mechanical, hydraulic or gas mixing systems that work in Goldilocks fashion: just the right amount of mixing, balanced by temperature and pH. The tanks are made of steel or concrete and are usually located above ground level. Continuously agitated digesters generally dilute the organic mixture to make mixing easier, such as a thick "soup" consistency.

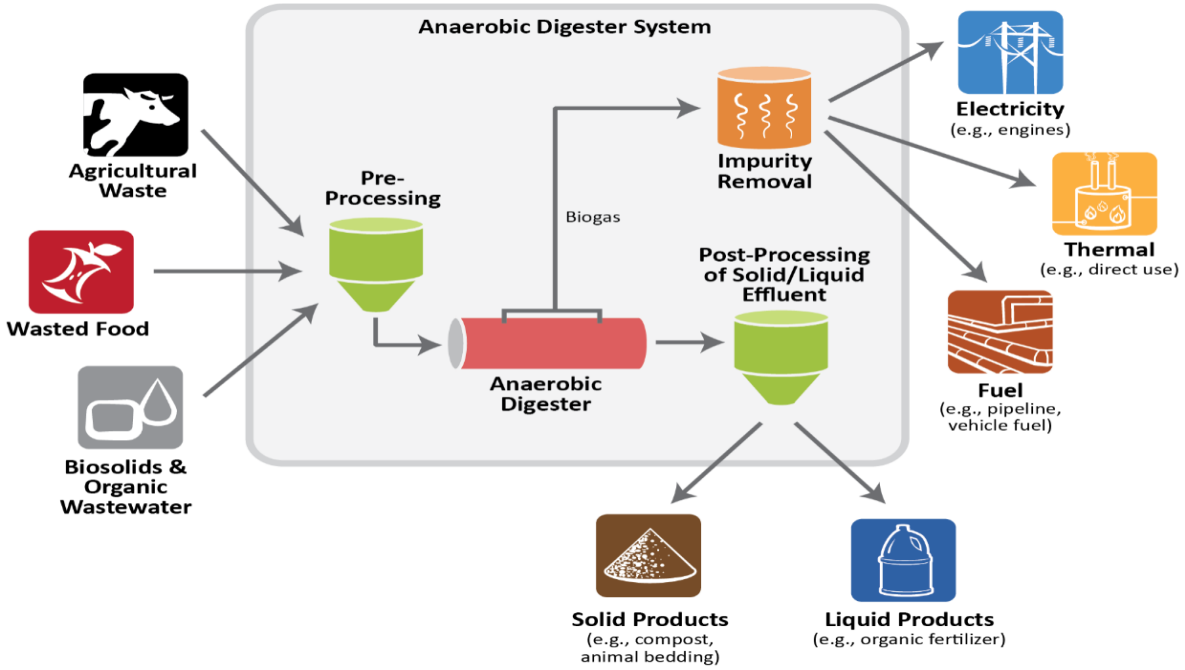

Figure 2: Illustration of input and output from anaerobic digester system

b. Plug-flow digesters: Plug-flow digesters accepts fresh organic feeds at one end and push them out the other with little or no mixing or heating process. They are usually designed as long, narrow concrete tanks with rigid or flexible covers. Most of the storage tanks are built entirely or partially underground to reduce heat demand. Plug flow systems are common on dairy farms where organic manure is obtained through scrapping.

c. Mixed Flow Digester: Mixed flow systems combine the characteristics of a fully mixed/continuously stirred digester with a vertical flow digester, which has more mixing than component flow but has a

higher solids content (less water) that the mixture completes. They are mixed and heated and are usually found above or below concrete tanks.

d. Dry digester: Instead of stirring the organic feeds, dry digester looks like a pile of materials enclosed in a tank, often resembling a garage. Internal sprinklers in the roof circulate liquids (including microorganisms and some raw materials) through the pile and are collected through floor slats for recycling. As with other digesters, the biogas migrates and accumulates at the top where it is collected in flexible air bladder above the digester. Dry digesters have the highest dry matter content and are best suited for rotting garden waste, sometimes composting material after decomposition by forcing air through strips of soil.

iii. Gasification: Gasification is a thermochemical process that converts carbonaceous materials into a synthetic gas (syngas) consisting of hydrogen, carbon monoxide, and other combustible gases. As shown in Figure 3, gasification converts MSW into usable synthesis gas or synthetic gas. Due to the production of these syngas, the combustion efficiency is very different. In the composting process, MSW is not a fuel but a raw material for a high-quality chemical reaction. Instead of producing only heat and electricity, as in waste-to-energy plants that use incineration, the syngas produced by combustion can be converted into valuable commercial products such as oil, transportation, chemicals, fertilizers and even natural gas. This cannot be achieved by incineration techniques.

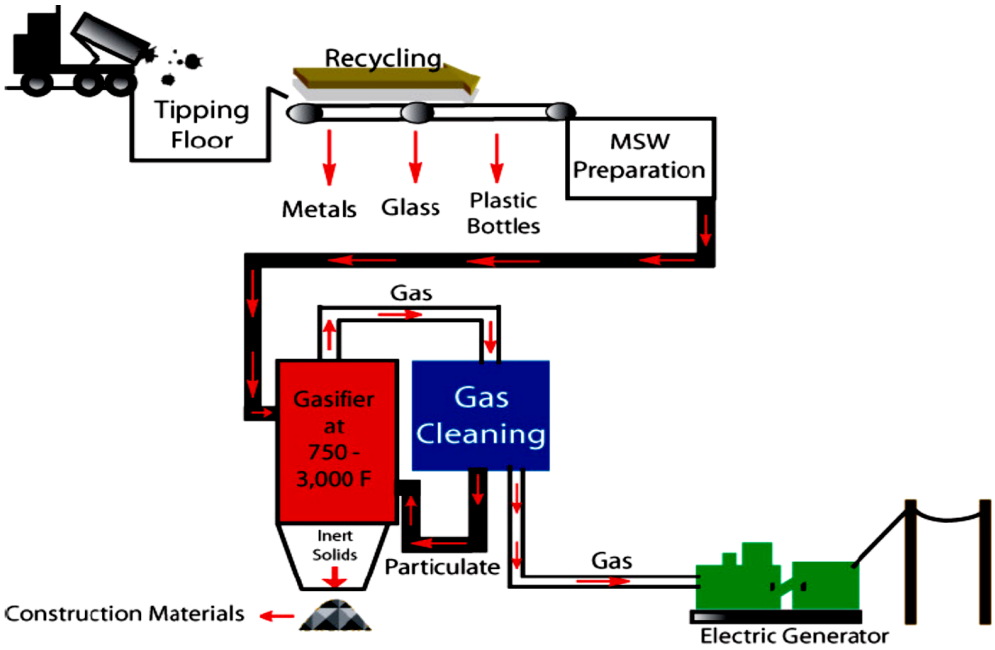

Figure 3: Incineration waste-to-energy conversion facility

Gasification is a specific process that converts carbon rich materials, such as MSW or biomass, into other forms of energy without burning them. Rather, gasification process converts solid and liquid waste into gas via a chemical reaction. This reaction combines organic feed materials with a little quantity oxygen (which is not sufficient to burn the feedstock) and disintegrates it into simple molecules, mainly a combination of CO and H_2. There are several forms of waste gasifiers, including plasma gasifiers which vary in size and classification of MSW that can be gasified as shown in Figure 4. Plasma is an ionized gas obtained when an electrical discharge is passed through the gas. The resulting lightning is an example of plasma found in nature. In this case, plasma torches and arcs convert electrical power into high thermal heat. The plasma torches and arcs can produce temperatures up to 10,000°F (5,500°C) during operation (Byun et al., 2012; Gandhi, 2015; Rohit et al., 2022).

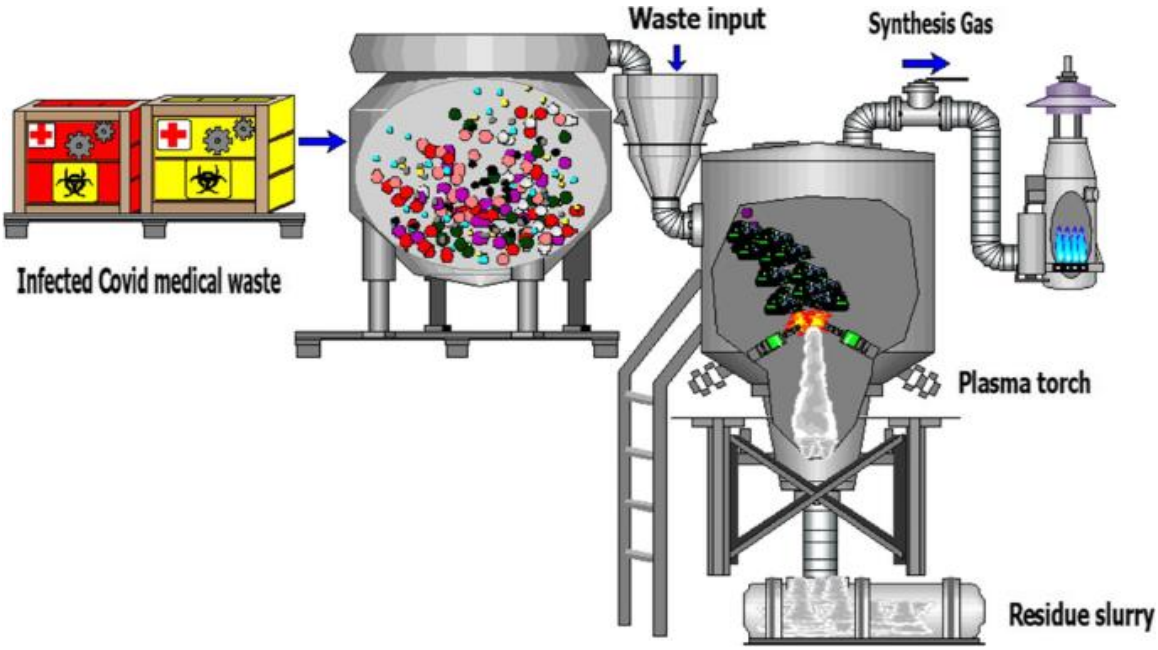

Figure 4: Illustration of plasma arc gasification waste treatment process

Some gasifiers are built for gasification of construction and demolition waste, others are used for municipal solid waste. Most gasification systems require some form of pre-treatment of municipal solid waste to extract inorganic materials that cannot be gasified (such as metals and glass). Some gasification systems require grinding, drying and sorting of the raw materials prior to introducing them into the gasifier. Syngas produced from the process can be used for electricity generation or as a feedstock for the production of chemicals and fuels. Proponents argue that gasification offers higher energy efficiency, lower emissions, and greater flexibility in waste types compared to incineration. However, the high capital costs, complex operation, and challenges in waste pre-processing limit its widespread implementation (Enebe et al., 2023; Gao et al., 2023; Afzal et al, 2023).

iv. Pyrolysis: Pyrolysis is a thermal decomposition process that converts waste materials into bio-oil, gas, and char in the absence of oxygen. Bio-oil can be used as a renewable fuel, while gas and char can be utilized for energy generation or as valuable by-products. Pyrolysis is the process by which heat is used to decompose biomass in the absence of oxygen (Hornung, 2012; Al Arni, 2023). Depending on the waste combination, segregation may by be carried out to separate non-combustible materials from combustible or carbonaceous products. The segregated waste materials are channelled into a feed mixer where for uniform mixing before being routed into a crusher for particle size reduction into less than 2mm. The raw materials are sent to a drying unit where any moisture associated with the raw materials is reduced to less than 10% moisture content by weight. In some cases where the food contains organic/moist materials, the unit can use natural and very moderate air temperatures to dry all raw feed materials for pyrolysis. The raw material that leaves the drying unit enters the pyrolysis reactor where it is thermally decomposed in the absence of oxygen. Three products are extracted from the pyrolysis process: synthesis gas rich in methane, pyrolysis oil and char (Banchapattanasakda et al., 2023).

During pyrolysis, the feedstock is gasifier at low temperature, giving off vaporised gas, known as oil-gas which initially flows into the manifold. The pyrolysed products exit the pyrolysis reactor in a gaseous state (that includes vapours, aerosols, and a suspended solid particles) into a cyclone separator which separates most of the solid particles (mostly char and ash) from the vapour, where they are then deposited to a char collector. In the manifold, heavy particles liquefy into heavier oil and drop in the heavy oil tank while the light gas-oil rises up.

The gases are then condensed in a quench system (heat exchanger), which converts most of the vapour into liquid Bio-Oil. The process produces vapour/gas that is condensed into liquid Bio-Oil also known as pyrolytic oil. The non-condensable gases (syngas) are recycled to supply the energy needed in the

process, while the Bio-Oil and char can be sold as commercial products. The pyrolysis process is presented in Figure 5a, and further illustrated in Figure 5b.

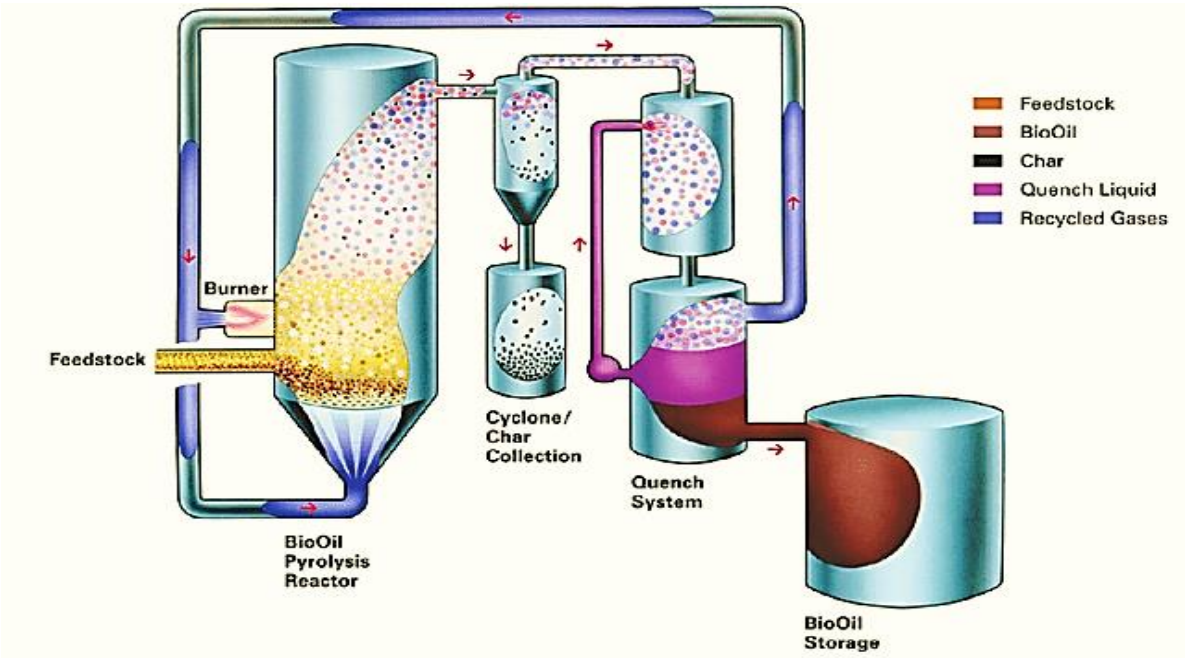

Figure 5a: Pictorial view of products recovery process from pyrolysis

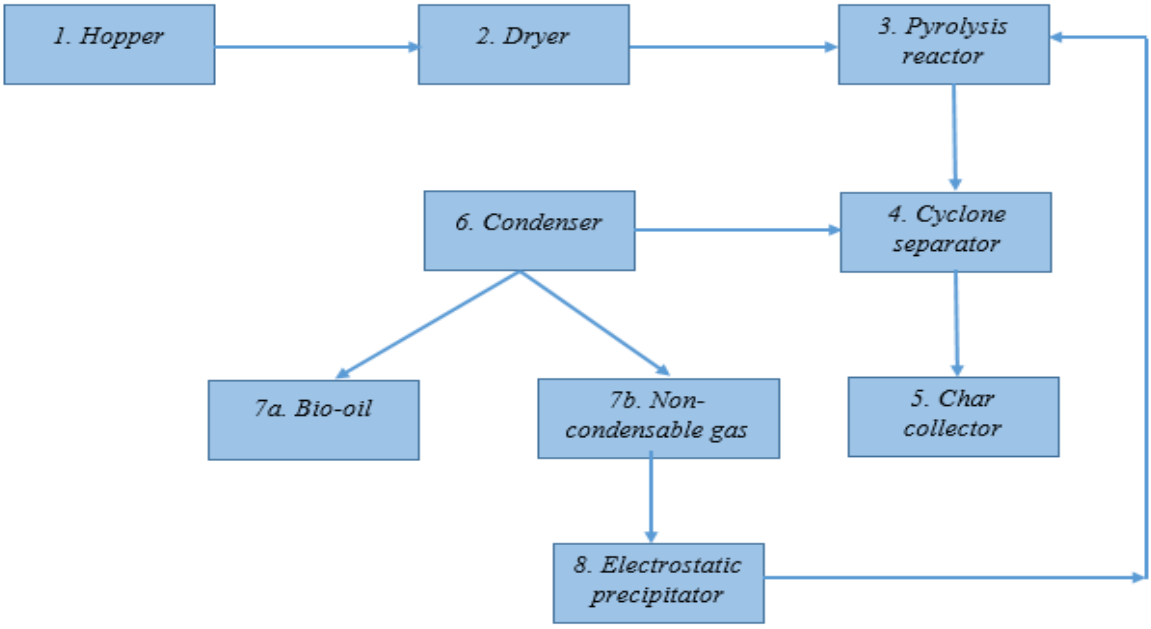

Figure 5b: Flow diagram illustrating products recovery from pyrolysis process

a. Feedstock is transferred from the waste bunker into the hopper.

b. The waste is conveyed from the hopper to dryer for drying before pyrolysis.

c. The waste is thermally disintegrated in the pyrolysis reactor.

d. The vapour coming out of the pyrolysis reactor contains solid char-like particles which are separated in the cyclone separator and collected in the char collector.

e. The char particles separated from the cyclone separator falls down to the char collector under gravity.

f. The vapour passing through the cyclone separator condenses in a condenser where bio-oil is collected as the condensate.

g. The bio-oil is subjected to further cleaning process before being cracked into other petroleum products.

h. The non-condensable gases are routed into electrostatic precipitator for further cleaning.

i. Electrostatic precipitator (ESP) is a filterless device that removes fine particles, like dust and smoke, from the non-condensable gas using the force of an induced electrostatic charge. The gas that exits the electrostatic precipitator is known as syngas which is used as fuel in the reactor.

Pyrolytic Reactor Technology advantageously operates at three distinct temperature ranges:

a. Low temperature pyrolysis (reaction vessel temperatures from 415-500ºC).

b. Medium temperature pyrolysis (reaction vessel internal temps from 500 and up to 750ºC).

c. High-temperature pyrolysis (reaction vessel internal temperatures from 750 to 1,100ºC).

Medium-temperature vacuum pyrolysis mode (420-650ºC): 53-60wt% feed stock conversion to pyrolytic oil or Bio-Oil; the vacuum pyrolytic oil is easily upgraded to a light oil with a calorific value of 42,000KJ/KG. BioOil from biomass feed stocks have also been successfully upgraded (Abdullahi et al., 2029; Al-Haj Ibrahim, 2020). High-temperature vacuum pyrolysis mode (800-1,100ºC) integrated with a proprietary catalyst which facilitates conversion to a methane-rich synthesis gas (100% nitrogen-free) that matches the calorific value of natural gas: producing a high calorific value synthesis gas at 19.35MJ/Nm3 (LHV) for biomass & upwards of 30.25MJ/Nm3 (LHV) for torrefied biomass. Clean-ups and stabilization of the bio-oil makes it more suitable for storage, downstream processing and end use. Clean-up can consist of filtering of particulate matter and ash before the bio-oil is condensed into liquid. That is the function of a cyclone separator. Stabilization typically involves mild hydro-treating, a process that uses hydrogen to remove contaminants such as sulphur, Nitrogen or in the case of bio-oils, oxygen.

a. The hydrogen prevents tar formation

b. Reduces impurities

c. Prevents coke build-up on the catalyst

d. Prevents the formation of polycyclic aromatic compounds

Hydro-treating occurs with high hydrogen pressures in the presence of catalyst. Oxygen is eliminated mostly as water along with some carbon dioxide. The eliminating oxygen creates a less reactive bio-oil with lower acidity. The less reactive bio-oil may be stored longer and is more suitable for use as a fuel oil. The less acidic bio-oil may be more readily accepted into current infrastructures by achieving chemical compatibility with infrastructure materials such as pipes, tanks reactors etc. Mild hydro-treating is usually followed by more severe hydro-treating which is required for the bio-oil to be suitable for use in a conventional petroleum refinery at several insertion points. They use technologies employed by existing refineries today, the bio-oil is sent to a hydro-cracking process which tailors the molecule sizes to be in the desired range for gasoline, diesel or jet fuels. Hydrocracking (HC) is defined as a process in which the components of gas oil fractions are (partially or completely) converted into lighter molecules under the influence of H_2 and in the presence of a catalyst (Bricker et al., 2015; Iplik et al., 2020). Basically, it processes heavy gasoils into more desirable products such as gasoline and diesel. Basically, the process cracks the high-boiling, high molecular weight hydrocarbons into lower-boiling, lower molecular weight olefinic and aromatic hydrocarbons and then hydrogenates them. Any sulfur and nitrogen present in the hydrocracking feedstock are, to a large extent, also hydrogenated and form gaseous hydrogen sulfide (H_2S) and ammonia (NH_3) which are subsequently removed. The result is that the hydrocracking products are essentially free of sulfur and nitrogen impurities and consist mostly of paraffinic hydrocarbons.

The carbonized particles recovered from the pyrolysis process are transported through the grate to the combustion chamber/furnace where pyrolysis of the carbon particles occurs (Jahirul et al., 2012; Pawelczyk et al., 2022; Rodrigues, 2022). This is a continuous process that takes place twenty four-hours-a-day and seven days a week. Temperatures range between 1000 and 1200ºC. This heat is not wasted, as water in the furnace walls is turned into steam. As shown in Figure 2, the steam enters the steam superheater, which converts the

wet steam into dry steam, then passes through the high-pressure turbine to rotate the turbine blades, and the turbine drives the generator. This generates enough electricity to power communities and provide power to the grid on a daily basis. Once the electricity is generated, the waste heat is used to provide heat to the community.

Advocates highlight the potential for reducing waste volumes, minimizing environmental impacts, and producing valuable products. However, challenges related to feedstock variability, process optimization, and bio-oil quality hinder its commercial viability. Waste-to-energy conversion technologies offer promising solutions for sustainable waste management and renewable energy generation. While each technology has its advantages and disadvantages, it is crucial to consider the specific waste composition, local regulations, and environmental impacts when selecting the most appropriate technology. Further research and development are necessary to address the challenges associated with these technologies and ensure their efficient and environmentally friendly implementation.

5. Factors Affecting Waste-to-Energy Technologies

Waste-to-energy (WtE) technologies have gained significant attention as a sustainable solution for waste management and energy generation. These technologies convert various types of waste into usable forms of energy, such as electricity, heat, or fuel. However, the successful implementation of WtE projects is influenced by several factors highlighted as follows (Baxter, 2007; Dong et al., 2019; Kumar et al., 2021; Alao et al., 2022; Williams et al., 2023)

i. Environmental Factors: Waste Composition: The composition of waste plays a crucial role in determining the efficiency and feasibility of WtE technologies. Different waste streams have varying energy content and combustion characteristics, affecting the overall energy recovery potential.

ii. Waste Pre-treatment: The pre-treatment of waste, including sorting, separation, and recycling, significantly impacts the efficiency of WtE technologies. Proper waste pre-treatment reduces the presence of contaminants, improves combustion efficiency, and minimizes environmental impacts.

iii. Emission Control: The control of emissions, such as greenhouse gases, particulate matter, and toxic pollutants, is essential for the environmental sustainability of WtE technologies. Advanced emission control technologies, such as scrubbers and filters, should be integrated into WtE plants to minimize air pollution.

iv. Capital Investment: The high capital costs associated with establishing WtE facilities pose a significant economic challenge. The availability of financial resources and investment incentives greatly influence the implementation of WtE projects.

v. Operational Costs: The operational costs, including waste collection, transportation, and plant maintenance, impact the economic viability of WtE technologies. Efficient waste management practices and economies of scale can help reduce operational expenses.

vi. Revenue Generation: The revenue generated from the sale of electricity, heat, or by-products, such as ash or biogas, is crucial for the financial sustainability of WtE projects. Favorable energy pricing policies and market conditions are essential for ensuring a steady revenue stream.

vii. Public Acceptance: The acceptance and support of local communities are vital for the successful implementation of WtE technologies. Public awareness campaigns, stakeholder engagement, and transparent decision-making processes can help address concerns and gain public trust.

viii. Regulatory Framework: The presence of supportive policies, regulations, and legal frameworks is crucial for promoting WtE technologies. Governments should provide clear guidelines, incentives, and permits to encourage the development of WtE projects.

ix. Social Impacts: The potential social impacts, such as noise, odor, and visual pollution, associated with WtE facilities should be carefully addressed. Proper site selection, architectural design, and community engagement can help mitigate these concerns.

x. Technological limitations: Some WtE processes require specific waste characteristics, limiting their applicability to certain waste streams.

6. Characteristics of Waste-to-Energy Technologies

Waste management has become a pressing global issue due to the increasing generation of waste and its adverse environmental impacts. Waste-to-energy (WtE) technologies have emerged as a potential solution to address this challenge. Its characteristics are as follows (Amber et al., 2012; Roy et al., 2023; Tian et al., 2023):

i. Efficiency and Energy Recovery: One of the primary characteristics of WtE technologies is their ability to convert waste into valuable energy resources. These technologies employ various processes such as incineration, gasification, and anaerobic digestion to extract energy from waste materials. The energy recovered can be utilized for electricity generation, heat production, or even as a fuel substitute. This characteristic makes WtE technologies a sustainable alternative to fossil fuels, reducing greenhouse gas emissions and dependence on non-renewable energy sources.

ii. Waste Reduction and Diversion: WtE technologies offer a significant advantage by reducing the volume of waste that would otherwise be sent to landfills. By diverting waste from landfills, these technologies contribute to the reduction of methane emissions, a potent greenhouse gas. Moreover, WtE technologies can handle various types of waste, including municipal solid waste, agricultural residues, and industrial waste, thereby providing a comprehensive waste management solution.

iii. Environmental Impacts: While WtE technologies offer several environmental benefits, it is crucial to consider their potential negative impacts. The combustion process in incineration-based WtE technologies releases pollutants such as nitrogen oxides, sulfur dioxide, and particulate matter. However, modern WtE facilities are equipped with advanced emission control systems to minimize these pollutants' release. Additionally, the proper management of ash generated during the process is essential to prevent soil and water contamination.

iv. Economic Viability: The economic viability of WtE technologies is a crucial aspect to consider. Initial investment costs for establishing WtE facilities can be substantial, including the construction of infrastructure and installation of advanced equipment. However, the long-term benefits, such as reduced waste management costs and revenue generation from energy sales, can offset these initial expenses. Additionally, the potential for job creation in the waste management sector further enhances the economic viability of WtE technologies.

v. Public Perception and Social Acceptance: The successful implementation of WtE technologies relies on public perception and social acceptance. Concerns regarding emissions, health risks, and the potential for negative impacts on nearby communities have led to opposition against some WtE projects. Therefore, it is crucial to engage in transparent communication, public consultations, and comprehensive environmental impact assessments to address these concerns and ensure social acceptance.

7. Applications of Waste-to-Energy Processes

The increasing global population and rapid industrialization have in recent times led to a significant rise in waste generation. Traditional waste management practices, such as landfilling and incineration, pose environmental and health risks. In this context, waste-to-energy (WtE) processes have emerged as a sustainable solution to address both waste management and energy needs. The applications of waste-to-energy processes are as follows (Mubeen and Buekens, 2019; Gutiérrez et al., 2021; Rezania et al., 2023):

i. Reduction of greenhouse gas emissions: WtE processes applied in mitigating climate change by diverting waste from landfills, where it decomposes and releases methane, a potent greenhouse gas.

ii. Resource conservation: WtE processes is applied in energy recovery from waste, reducing the reliance on fossil fuels and promoting a circular economy.

iii. Land use optimization: Application of WtE facilities require less land compared to landfill sites, allowing for better land management and potential reuse.

iv. Electricity production: WtE processes can be applied in the generation of electricity through combusting waste or utilizing biogas produced during anaerobic digestion.

v. Heat generation: Application of WtE facilities can provide heat for industrial processes, district heating, or residential use, reducing the demand for fossil fuel-based heating systems.

vi. Waste reduction and diversion: WtE application minimizes the volume of waste sent to landfills, extending their lifespan and reducing the need for new landfill sites.

vii. Hazardous waste treatment: Application WtE technologies can effectively treat hazardous waste, reducing the risks associated with improper disposal.

viii. Job creation: The implementation and operation of WtE facilities can create employment opportunities, contributing to local economies.

ix. Revenue generation: WtE application can generate revenue through the sale of electricity, heat, or recovered materials, offsetting operational costs.

Waste-to-energy applications offer a sustainable solution to address the challenges of waste management and energy generation. By converting waste into usable forms of energy, WtE technologies contribute to environmental protection, resource conservation, and economic development. However, careful consideration of technological limitations, environmental concerns, and public acceptance is necessary to ensure the successful implementation of WtE projects.

8. Advantages of Waste-to-Energy Technologies

Waste-to-energy technologies offer numerous advantages over other forms of energy recovery technologies as well as traditional waste disposal methods, such as landfilling and incineration, have proven to be unsustainable and detrimental to the environment. Advantages of waste-to-energy technologies are enumerated as follows (Miito and Banadda, 2016; Seltenrich, 2016; Sun et al., 2020):

i. Environmental Benefits: WtE technologies offer several environmental advantages. Firstly, they help reduce the volume of waste that ends up in landfills, thereby minimizing the associated environmental risks, such as groundwater contamination and greenhouse gas emissions. WtE facilities can reduce landfilling by up to 90%. Secondly, WtE technologies can significantly reduce the emission of harmful pollutants compared to traditional incineration methods. Advanced WtE systems employ state-of-the-art air pollution control technologies, ensuring compliance with stringent emission standards.

ii. Energy Generation: One of the key advantages of WtE technologies is their ability to generate clean and renewable energy. By converting waste into heat or electricity, WtE facilities contribute to the diversification of energy sources and reduce reliance on fossil fuels. The energy produced from waste can be utilized for various purposes, including powering homes, industries, and even transportation. For instance, the Waste-to-Energy Research and Technology Council (WTERT) estimates that a typical WtE facility can generate enough electricity to power approximately 10,000 households.

iii. Resource Recovery: WtE technologies enable the recovery of valuable resources from waste streams. Through processes like anaerobic digestion and thermal treatment, organic waste can be converted into biogas or biofuels, which can be used as renewable energy sources. Additionally, WtE facilities often incorporate advanced sorting and recycling systems to recover recyclable materials, further reducing the need for raw material extraction. This resource recovery aspect of WtE technologies contributes to the circular economy concept, promoting sustainable resource management.

iv. Economic Opportunities: The implementation of WtE technologies can create significant economic opportunities. Firstly, the construction and operation of WtE facilities generate employment opportunities, both during the construction phase and in the long term. Moreover, the revenue generated from the sale of electricity, heat, or recovered resources can offset the costs associated with waste management, making the overall process economically viable. A study conducted by the World Bank estimates that WtE projects can create up to 50% more jobs compared to landfilling or incineration.

Waste-to-energy technologies offer numerous advantages, making them a promising solution for sustainable waste management and energy generation. By reducing environmental pollution, generating clean energy, recovering valuable resources, and creating economic opportunities, WtE technologies contribute to a more

sustainable and circular economy. However, it is crucial to ensure proper regulation, monitoring, and public awareness to address any potential concerns and maximize the benefits of these technologies.

9. Disadvantages of Waste-to-Energy Technologies

Waste-to-energy (WtE) technologies are employed in the conversion of waste into energy, reducing landfill space and dependence on fossil fuels. However, despite their apparent benefits, WtE technologies also come with several disadvantages that need to be carefully considered. These disadvantages include (Moharir et al., 2019; Karmakar et al., 2023; Dadario et al., 2023; Tan, 2013):

i. Environmental Concerns: One of the primary disadvantages of WtE technologies is their potential negative impact on the environment. The incineration process releases various pollutants, including greenhouse gases, heavy metals, and dioxins, which contribute to air pollution and climate change. Additionally, the ash produced during incineration may contain toxic substances that require careful disposal to prevent soil and water contamination

ii. Health Risks: The emissions generated by waste incineration can pose significant health risks to nearby communities. Studies have linked exposure to incinerator emissions with respiratory problems, cardiovascular diseases, and even cancer. The release of toxic substances during the incineration process can also have long-term health implications for both humans and wildlife.

iii. Economic Viability: While waste-to-energy technologies may seem economically attractive, they often face financial challenges. The high initial capital investment required for building and operating WtE plants can be a significant barrier, especially for developing countries. Moreover, the fluctuating prices of energy and waste disposal can affect the profitability and long-term sustainability of these projects.

iv. Waste Hierarchy Disruption: WtE technologies can potentially disrupt the waste hierarchy, which prioritizes waste reduction, reuse, and recycling over disposal methods. By diverting waste to incineration, the focus on waste reduction and recycling may diminish, leading to a missed opportunity for sustainable waste management. This can hinder the transition towards a circular economy and sustainable resource management.

v. Limited Waste Diversion: WtE technologies primarily focus on the incineration of waste, which means that valuable resources are lost in the process. Instead of promoting waste reduction and recycling, these technologies encourage the continued generation of waste, perpetuating the linear "take-make-dispose" model (Brunner et al., 2018). This limited waste diversion can hinder efforts to achieve waste reduction targets and promote a more sustainable waste management approach.

While waste-to-energy technologies offer potential benefits in terms of waste management and energy generation, it is crucial to acknowledge their disadvantages. The environmental concerns, health risks, economic viability, disruption of waste hierarchy, and limited waste diversion associated with these technologies should be carefully considered. To ensure sustainable waste management, a comprehensive approach that prioritizes waste reduction, reuse, and recycling should be adopted, with waste-to-energy technologies playing a complementary role rather than being the sole solution.

10. Conclusion

The history of waste-to-energy conversion processes demonstrates the continuous efforts to address waste management challenges while harnessing renewable energy sources. From the early days of incineration to the modern innovations in gasification and pyrolysis, significant progress has been made in improving the efficiency and environmental performance of waste conversion technologies. Waste-to-energy technologies offer a promising solution for waste management and renewable energy generation. However, the successful implementation of these technologies is influenced by various factors, including waste composition, pre-treatment, emission control, capital investment, operational costs, revenue generation, public acceptance, regulatory framework, and social impacts. To ensure the sustainable adoption of WtE technologies, policymakers, industry stakeholders, and communities must collaborate to address these factors effectively.

By considering the environmental, economic, and social implications, waste-to-energy technologies can contribute significantly to a more sustainable and circular economy.

Waste-to-energy technologies possess several characteristics that make them a promising solution for sustainable waste management. Their ability to recover energy, reduce waste volume, and mitigate greenhouse gas emissions contributes to a circular economy and a cleaner environment. However, careful consideration of environmental impacts, economic viability, and public perception is necessary for the successful implementation of WtE technologies. By understanding these characteristics, policymakers can make informed decisions to promote the adoption of WtE technologies as part of a comprehensive waste management strategy Successful implementation of waste-to-energy technologies requires a comprehensive approach that considers environmental impacts, technological advancements, stakeholder engagement, and supportive policies. By adhering to the following recommendations in this study, governments and policymakers can effectively harness the potential of WtE technologies to address waste management challenges while promoting sustainable development.

i. Emphasize the Importance of Proper Waste Management: To effectively implement WtE technologies, it is crucial to prioritize waste reduction, reuse, and recycling. Governments and local authorities should promote waste segregation at source, encourage public awareness campaigns, and establish robust recycling infrastructure. By reducing the amount of waste sent to landfills, WtE technologies can focus on converting residual waste into energy.

ii. Promote Technological Advancements: Continuous research and development in WtE technologies are essential to improve efficiency, reduce emissions, and enhance overall performance. Governments should invest in research institutions and provide financial incentives to encourage innovation in this field. Collaboration between academia, industry, and policymakers can facilitate the development of advanced WtE technologies.

iii. Assess Environmental Impacts: Before implementing WtE technologies, a comprehensive environmental impact assessment (EIA) should be conducted. This assessment should evaluate potential air and water pollution, greenhouse gas emissions, and the overall ecological footprint. The findings of the EIA should guide the selection of appropriate WtE technologies that minimize environmental harm. Also, Emissions from WtE facilities must be carefully managed to minimize air pollution and ensure compliance with regulatory standards.

iv. Consider Local Context and Stakeholder Engagement: Each region has unique waste characteristics, energy demands, and social dynamics. Therefore, it is crucial to consider the local context when selecting WtE technologies. Engaging stakeholders, including local communities, environmental organizations, and industry representatives, is essential to ensure transparency, address concerns, and build public acceptance. Community engagement and education are crucial to address concerns related to odour, noise, and potential health risks associated with WtE facilities.

v. Encourage Policy Support and Regulatory Frameworks: Governments should develop supportive policies and regulatory frameworks to promote the adoption of WtE technologies. These policies should include incentives such as feed-in tariffs, tax benefits, and subsidies to attract private investments. Additionally, clear guidelines and standards should be established to ensure the safe and sustainable operation of WtE facilities.

vi. Foster International Collaboration: International collaboration and knowledge sharing can accelerate the deployment of WtE technologies. Governments should encourage partnerships between countries to exchange best practices, share technological advancements, and jointly address common challenges. International organizations, such as the United Nations and World Bank, can play a vital role in facilitating such collaborations.

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SIMULATION PERFORMANCE ANALYSIS OF ROUTING PROTOCOLS USING ENERGY MODEL

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ABSTRACT

This paper focuses on the simulation-based performance analysis of two widely adopted MANET routing protocols: Ad Hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR). The evaluation is centered on a detailed examination of energy consumption, specifically in transmit mode, receive mode and idle mode and investigates the percentage distribution of energy consumption in each of these operational modes. Results from the simulation analysis reveal insights into the energy efficiency of AODV and DSR in various operational modes. This paper presents a detailed breakdown of the percentage distribution of energy consumption, shedding light on how each protocol allocates energy resources during different network states. These findings contribute to a comprehensive understanding of the trade-offs associated with AODV and DSR, assisting network designers and researchers in selecting routing protocols tailored to specific application requirements. This research exploration of energy consumption in transmit, receive, and idle modes paves the way for the development of more resilient and energy-efficient communication solutions, addressing the dynamic and resource-constrained nature of mobile and ad hoc environments.

Keywords: Wireless Network, AODV, DSR, Energy Model, Performance matrices Qualnet Tool

1. Introduction

Mobile Ad-Hoc Networks (MANETs) [1-6] represent dynamic wireless networks where devices, or nodes, communicate with each other without a fixed infrastructure. These networks are particularly relevant in scenarios where establishing a pre-existing communication infrastructure is impractical or impossible, such as in disaster-stricken areas, military operations, or temporary gatherings. Routing protocols play a pivotal role in MANETs by determining how data is transmitted from one node to another. Given the absence of a centralized infrastructure, routing protocols enable nodes to collaboratively establish communication paths. These protocols are crucial for the seamless functioning of MANETs, ensuring efficient and reliable data exchange in dynamic and ever-changing network topologies[7-9].

Energy efficiency is a paramount consideration in the context of mobile and ad-hoc environments. Devices in these networks, often powered by batteries, operate in resource-constrained settings. Optimizing energy consumption is critical to prolonging the operational lifespan of nodes, reducing the need for frequent battery replacements, and enhancing the overall sustainability of the network. Two routing protocols, Ad Hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR), are particularly noteworthy in the realm of MANETs. AODV is an on-demand routing protocol that establishes routes only when necessary, minimizing the overhead associated with maintaining constant connectivity. DSR, on the other hand, relies on source routing, where the complete route is included in the packet header, offering flexibility in adapting to changing network conditions. The focus on AODV and DSR in this research is driven by their prevalence and widespread adoption in various MANET applications. Understanding how these protocols perform, especially in terms of energy efficiency across different operational modes, contributes significantly to the optimization and adaptation of MANETs in real-world scenarios. By delving into their energy consumption patterns in transmit, receive, and idle modes, this research aims to provide valuable insights that can guide the design, implementation, and enhancement of routing protocols in energy-constrained mobile and ad-hoc environments[10-15].

2. Energy Model for Wireless Networks

In the context of wireless networks, an energy model is a representation of how energy is consumed by various components such as nodes, radios, and communication links. Modeling energy consumption is crucial for understanding the power requirements and optimizing the energy efficiency of wireless communication systems. Different wireless communication technologies and protocols may have different energy models to account for their specific characteristics. Here are some common aspects considered in energy models for wireless networks[16-20].

- **Transmitter Power Consumption:** This includes the power consumed when a device is transmitting data. It depends on factors such as the transmission power level and the distance over which the data is transmitted.
- **Receiver Power Consumption:** The power consumed when a device is in the receiving mode, processing incoming signals. It may vary based on factors such as the signal strength and modulation schemes.
- **Idle Mode Power Consumption:** Even when a device is not actively transmitting or receiving data, it still consumes power in the idle state. This includes power used by the device's electronics to maintain connectivity and be ready for communication.
- **Sleep Mode Power Consumption:** Many wireless devices have a low-power sleep mode to conserve energy when not actively participating in communication. The power consumption in sleep mode is typically lower than in the active or idle mode.

3. Methodology

A. **Simulation Environment and Parameters**

- **Simulation Tool:** The simulation is conducted using the QualNet tool, a widely used discrete-event network simulation platform. QualNet facilitates the modeling and analysis of communication networks, allowing for the evaluation of various protocols and scenarios [22].
- **Network Scenario:** A representative Mobile Ad-Hoc Network (MANET) scenario is designed, considering factors such as node density, mobility patterns, and communication patterns. The simulation scenario aims to capture realistic conditions that nodes might encounter in dynamic, ad-hoc environments [23].

B. Simulation Parameters

- **Node Mobility:** Nodes exhibit varying degrees of mobility to emulate real-world scenarios. Random Waypoint or Random Walk models are employed to simulate node movement [24].
- **Communication Patterns:** Different communication patterns, such as point-to-point, multicast, and broadcast, are considered to assess the protocols' performance under various scenarios [25-28].
- **Traffic Patterns:** Varied traffic loads, including bursty and continuous data transmission, are simulated to evaluate protocol behavior under different levels of network activity [29-30].

4. Comparative Analysis of Energy Consumption Patterns: AODV vs. DSR

- **Transmit Mode:** AODV: Demonstrates a slightly elevated energy consumption during data transmission compared to DSR. This can be attributed to the on-demand nature of AODV, involving periodic route discovery and maintenance. DSR: Displays efficient energy utilization during transmission, leveraging source routing to minimize overhead. The energy consumption pattern aligns with its proactive approach to route establishment.
- **Receive Mode:** AODV: Exhibits a lower percentage of energy consumption during reception, indicating effective handling of incoming packets. The reactive nature of AODV contributes to this energy-efficient reception mode. DSR: Displays a comparatively higher energy consumption during

reception. Source routing, while efficient for transmission, may introduce processing overhead during packet reception.

- **Idle Mode:** AODV and DSR: Demonstrate similar energy consumption patterns during idle periods. Both protocols effectively manage power consumption when nodes are not actively engaged in communication.
- **Idle States:** AODV and DSR: Both protocols demonstrate a balanced and comparable energy consumption pattern during idle periods. The idle mode power consumption is effectively managed, contributing to the sustainability of nodes during network inactivity.

5. Simulation Results

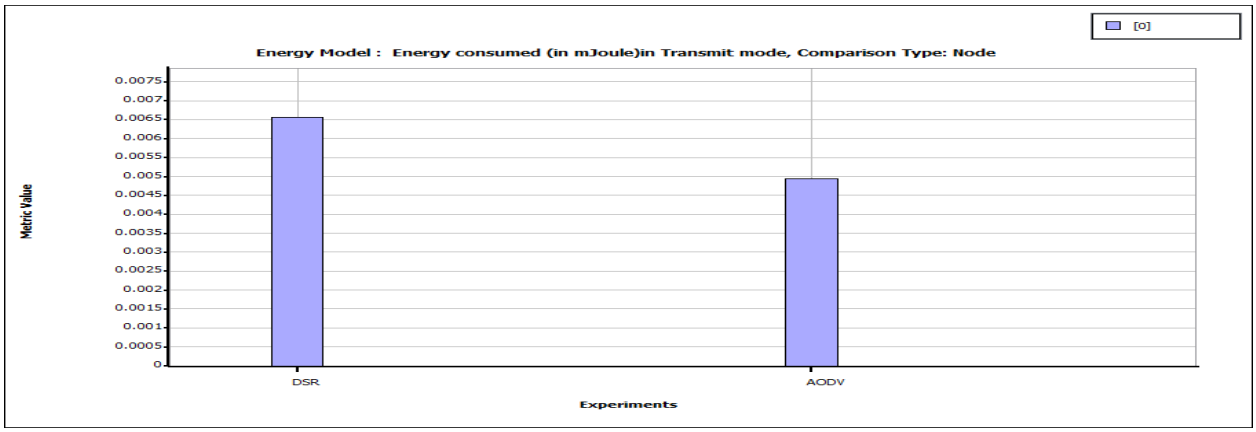

Figure 1: Energy Consumed in Transmit Mode

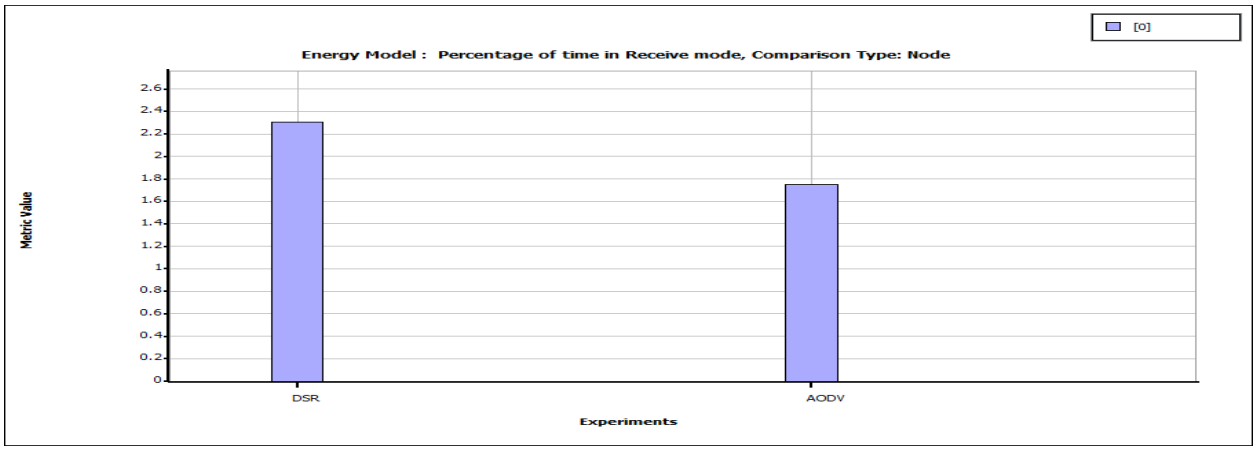

Figure 2: Energy Consumed in Receive Mode

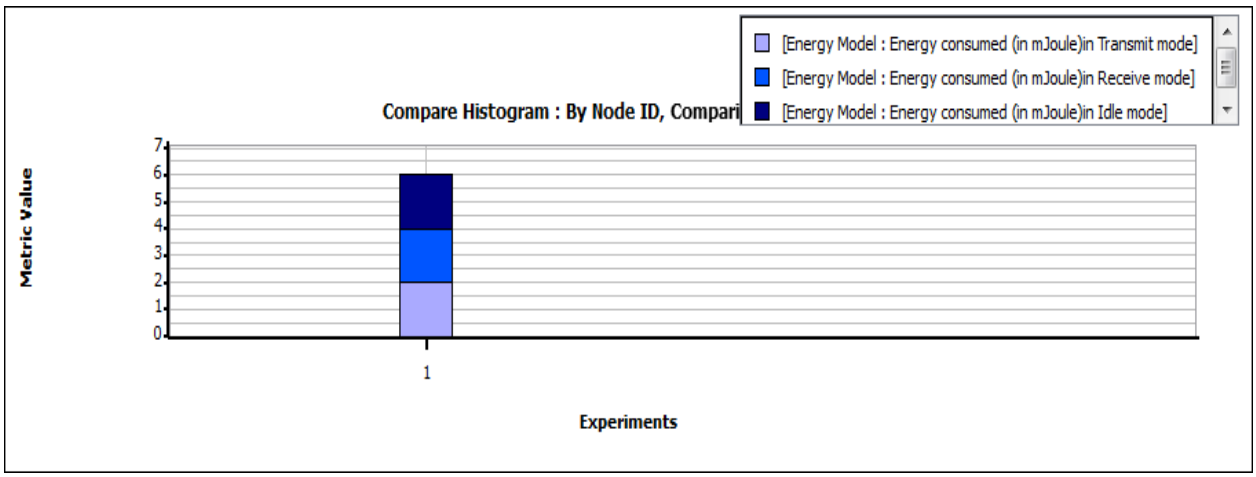

Figure 3: Energy Consumed in Transmit Mode, Receive and Idle Mode

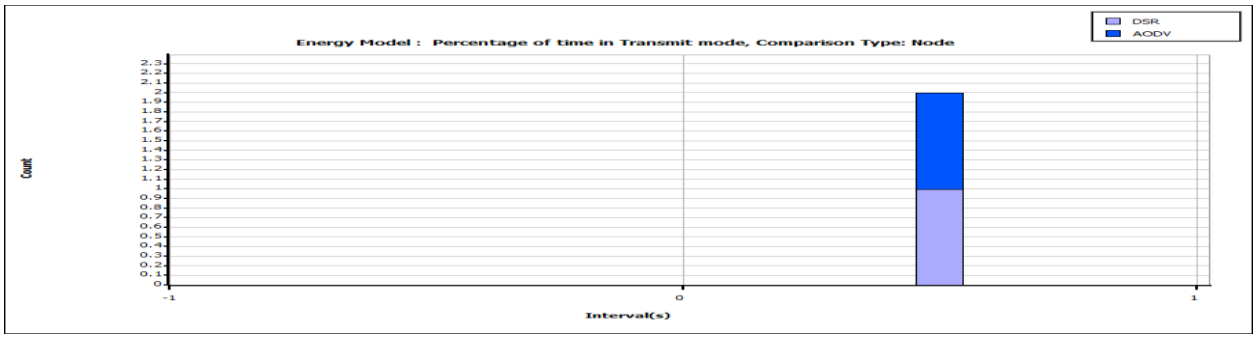

Figure 4: Percentage of time in Transmit Mode

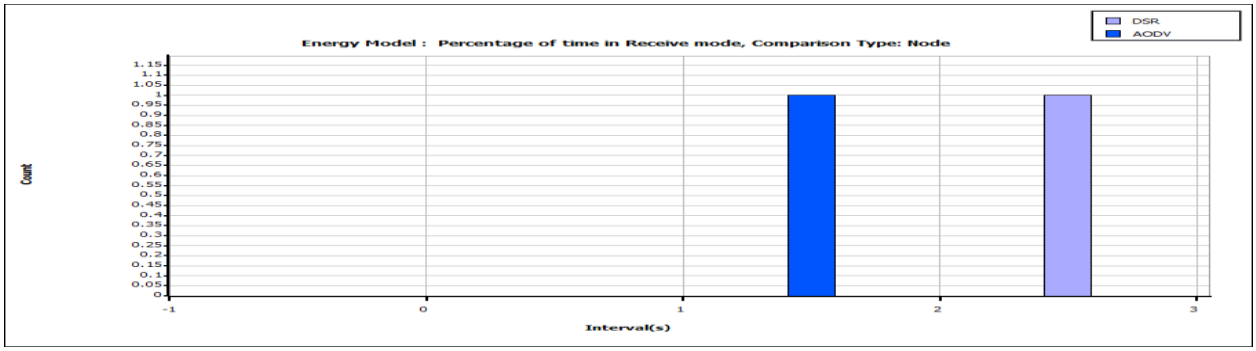

Figure 5: Percentage of time in Receive Mode

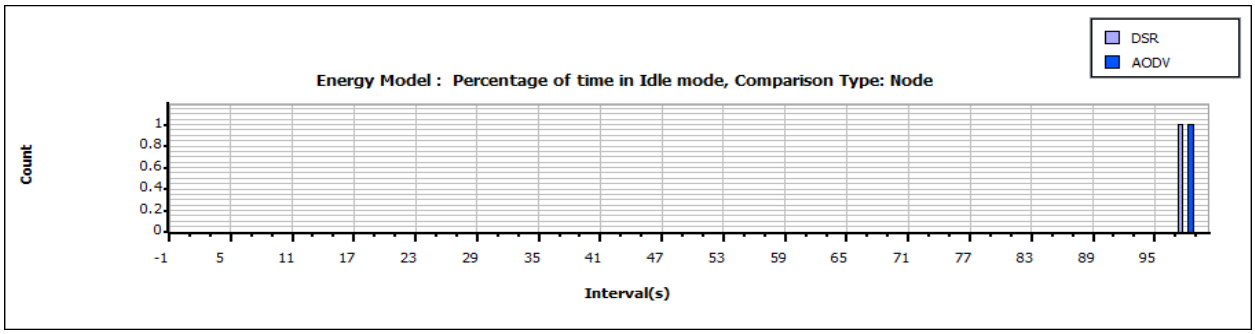

Figure 6: Percentage of time in Idle Mode

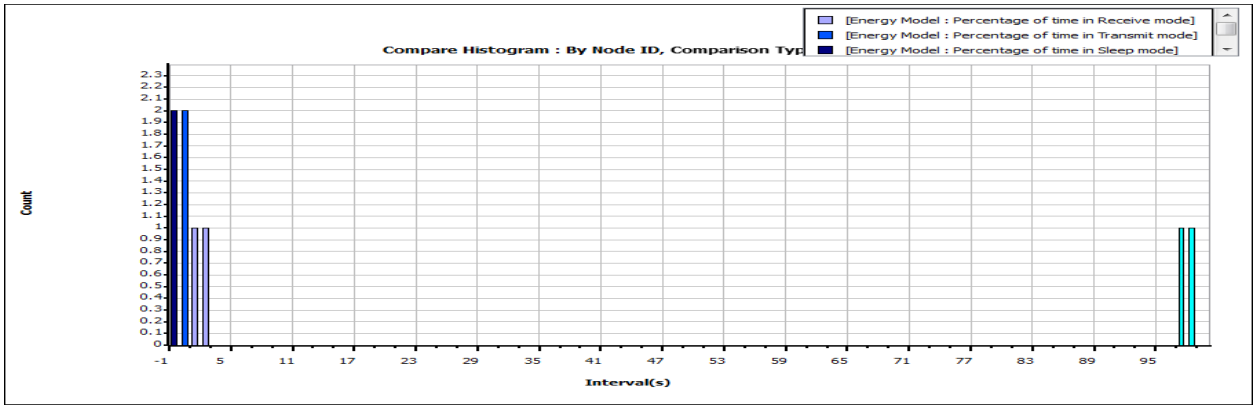

Figure 7: Percentage of time in Transmit Mode, Receive and Idle Mode

6. Conclusion

The research provides a comprehensive analysis of the energy consumption patterns of Ad Hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR) protocols in Mobile Ad-Hoc Networks (MANETs). Both AODV and DSR exhibit distinct energy consumption patterns in transmit, receive, and idle modes. AODV demonstrates slightly higher energy consumption during data transmission, attributed to its on-demand route discovery mechanism. DSR leverages source routing for efficient transmission but may incur additional processing overhead during packet reception. AODV and DSR showcase similar and efficient energy consumption during idle periods, reflecting effective power management during network inactivity. AODV's reactive route discovery contributes to lower receive mode energy consumption, while DSR's source-routing approach influences higher energy consumption during reception. AODV adapts well to changes in network topology through dynamic route discovery, contributing to adaptability during active communication. DSR relies on pre-established source routes, showcasing efficiency in certain scenarios but potentially limiting adaptability to dynamic network changes.

7. References

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A LEAST SQUARE- LAPLACE TRANSFORM METHOD FOR SOLVING VOLTERRA INTEGRAL EQUATION WITH HIGHLY OSCILLATORY BESSEL KERNELS

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ABSTRACT

The propose new numerical tools for computation of integrals equation having oscillatory special functions like Bessel function and also any types of function on right hand side which may be oscillatory or non-oscillatory. We consider The Volterra integral equation of Oscillatory type. The Laplace transform of the right hand side is difficult to compute. We approximate the proposed model by the combination of the Least Square Series method and the Laplace transform. The right-hand side of the proposed integral equations will be converted in a special series, which enable us to compute the Laplace transform in simple manner. The Laplace transform will be applied to convert the model into some simple form, and will solve it for transformed solution. The solution will then be recovered with numerical inverse Laplace transform by incorporating some suitable contour in the complex plane. In doing this we aim to convert the oscillatory problem into very smooth non oscillatory problems and the to find the solution with great accuracy.

Keywords: Volterra integral equation, Bessel function, Least Square Series, Laplace transform.

1: Introduction

In the current present paper we were approximate the Volterra integral equation with Bessel kernel and will find the numerical form of the solution. Some earlier work relevant to approximate the current problem can be found in the reference work [1,2]. In these references, the numerical as well as analytical methods have been developed. In the present MS research proposal, we are concerned with the numerical solution of Volterra integral equation defined by the following equation (1)

$$\int_a^x J_\nu \omega(x-t)u(t)dt = g(x)\,, \quad x \in [0,1]\,, \quad \nu > -1, \qquad (1)$$

where ω are oscillation parameters J_ν is the Bessel function and $g(x)$ is any function which may be oscillatory or non-oscillatory and $u(t)$ is unknown function to be find some efficient numerical methods have been used recently (see, for example, [3,4] and references therein). The essential application of problem (1) is highly oscillation parameter ω , due to which the kernel of Bessel types function which is highly oscillatory . It means that the most important methods like Galerkin method slandered collocation method are suffered due to the highly oscillation parameter. To overcome this difficulties, we used Least Square in Laplace transform methods.

We were approximate the proposed model by combination the Least Square Series and Laplace transform. Since the kernel involved are of difference type, the oscillation parameters and right-hand side contain oscillatory function. The Laplace transform along with Least Square series will apply to the propose model. Then inverse Laplace will be approximated numerically.

2: Least Square Series and Laplace Transform method of Volterra Integral Equation

We expressed $g(x)$ in the form of Least Square series [3], as

$$g(x) = \sum_{l=1}^{5} \sum_{l=0}^{3} a_{jl} x^l e^{-jx} \qquad \text{where} \quad x \in [0,T] \qquad (2)$$

Let $g(x)$ is be a function of class A function then we define, The Laplace transform is define as

$$G(P) = \int_0^{\infty} e^{-p\tau}\, g(x)d\tau \qquad (3)$$

The inverse transform is expressed as

$$g(x) = 1/2\pi i \int_{c-i\infty}^{c+i\infty} e^{p\tau}\, G(P)dp \qquad (4)$$

This pairs of transform are very suitable for the approximate solution of volterra integral equation. For more detail studied transform book may be very suitable [5]

Laplace transform of Bessel function in form of

$$L[j_v]=\frac{w^v}{(z+\sqrt{p^2+w^2})\sqrt{p^2+w^2}} \qquad (5)$$

The Laplace transform of Least Square series for g(x) as

$$L[g(x)] = L(\sum_{l=1}^{5} \sum_{l=0}^{3} a_{ji} x^l e^{-jx}) \qquad (6)$$

$$L(g(x))= \sum_{l=1}^{5} \sum_{l=0}^{3} \frac{a_{ji}\ l!}{(s+j)^{l+1}}$$

$$U(x)=\frac{(\sum_{l=1}^{5} \sum_{l=0}^{3} \frac{a_{ji}\ l!}{(s+j)^{l+1}})(\sqrt{p^2+w^2})\sqrt{p^2+w^2})}{w^v}$$

3: Solution of Integral Equation by Least Square and Laplace Transform method.

We apply the developed method which is based on Least Square and Laplace transform method to integral equation with Bessel kernel as follow

$$\int_a^x J_v \omega(x-t)u(t)dt = g(x)\,, \qquad x \in [0,1], \qquad v > -1, \qquad (7)$$

The solution of equation (1) in the form of

$$L[u(t)]L[j_v] = L[\sum_{l=1}^{5} \sum_{l=0}^{3} a_{ji} x^l e^{-jx}\ ] \qquad (8)$$

$$L[u(t)] = \frac{L[\sum_{l=1}^{5} \sum_{l=0}^{3} a_{ji} x^l e^{-jx}\ ]}{L[j_v]} \qquad (9)$$

Putting equation (5) and (6) in equation (9), we get

$$L[u(t)] = \frac{(\sum_{l=1}^{5} \sum_{l=0}^{3} \frac{a_{ji}\ l!}{(s+j)^{l+1}})(\sqrt{p^2+w^2})\sqrt{p^2+w^2})}{w^v} \qquad (10)$$

The integral equation define above can be converted in to Gaussian plane and then the result can be getting in the form of Gaussian line integral along with some suitable path with the utilization of some quadrature rules. The solution formula recovered in this format is given as.

$$u(t) = 1/2\pi i \int_Q e^{p\tau}\, G(P)dp \qquad (11)$$

so we can use parabolic path which is suitable for any type of integral equation and also need less nodal points and getting good accuracy.

$$Q = W + \vartheta(1 - \sin\,(g - ip)) \qquad (12)$$

where W, ϑ, g are the parameters in equation (12)

For,

$$p = p(f), \qquad s_n = s(f_n), \qquad f_n = nk$$

So equation (12) in the form trapezoidal rule we get

$$L[g(x)] = \sum_{-J}^{J} 1 \exp(Sjt) G(P) dp$$

Table for: Laplace its Inverse Function.

S. No	$\mathcal{L}\, g$(s)	Laplace	Inverse Laplace	g(s)
01.	$\mathcal{L}(s^n)$	$\frac{n!}{p^{n+1}}$	$\frac{n!}{p^{n+1}}$	(s^n)
02.	$\mathcal{L}(e^{as})$	$\frac{1}{p-b}$	$\frac{1}{p-b}$	(e^{bs})
03.	$\mathcal{L}(sinbs)$	$\frac{1}{p^2+b^2}, p > 0$	$\frac{1}{p^2+b^2}, p > 0$	$(sinbs)$
04.	$\mathcal{L}(sinbs)$	$\frac{s}{p^2+b^2}, p > 0$	$\frac{s}{p^2+b^2}, p > 0$	$(sinbs)$

4: Analysis of LS-LT (Least Square-Laplace transform Method) by solving Example

Example 1: Consider the following VIE (Voltterra integral equation) is given as,

$$\int_a^t J_v \omega(t-z) u(z) dz = t^2 e\text{^}t^2 \quad , \; t \in [0,1], \quad \nu = 1 \tag{14}$$

Where the $\mathcal{L}(t^2 e\text{^}t)$ is not available so using Least Square and Laplace transform methods

The solution of equation (14) in the form of

$$L[u(t)] L[j_v] = L[\sum_{l=1}^{5} \sum_{l=0}^{3} a_{ji} x^l e^{-jx} \;] \tag{15}$$

$$L[u(t)] = \frac{L[\sum_{l=1}^{5} \sum_{l=0}^{3} a_{ji} x^l e^{-jx} \;]}{L[j_v]} \tag{16}$$

Putting equation (5) and (6) in equation (9), we get

$$L[u(t)] = \frac{(\sum_{l=1}^{5} \sum_{l=0}^{3} \frac{a_{ji}\; l!}{(s+j)^{l+1}})(\sqrt{p^2+w^2})\sqrt{p^2+w^2})}{w^v} \tag{17}$$

The integral equation define above can be converted in to Gaussian plane and then the result can be getting in the form of Gaussian line integral along with some suitable path with the utilization of some quadrature rules. The solution formula recovered in this format is given as.

$$u(z) = 1/2\pi i \int_Q e^{p\tau} F(P) dp \tag{18}$$

so we can use parabolic path which is suitable for any type of integral equation and also need less nodal points and getting good accuracy.

$$Q = W + \vartheta(1 - \sin(g - ip)) \tag{19}$$

where W, ϑ, g are the parameters in equation (19)

For,

$$p = p(f), \qquad s_n = s(f_n), \qquad f_n = nk$$

So equation (12) in the form trapezoidal rule we get

$$u(z) = \sum_{-J}^{J} 1 \exp(Sjt) F(P) dp$$

Table 1: The approximate solution for the example 1 the results obtained by the present method when the quadrature points N=50 and oscillation parameter w=1000.

t	**0.1**	0.4	1
Uapp	0.1036	$0.18886e+003$	2.7171e+003
Uexct[2]	$0.1e+003$	0.188e+003	2.729e+003
Uapp[2]	0.1010e+003	0.1877e+003	2.7182e+003
Error	0	1.165e^-15	6.70e^-11

Example 2: Consider the following VIE (Voltterra integral equation) is given as,

$$\int_a^t J_v \omega(t-z)u(z)dz = sint,\ t \epsilon [0,1], \qquad \nu = 0 \qquad (1)$$

Where the $\mathcal{L}(sint)$ is available so using Laplace transform methods

The solution of equation (1) in the form of

$$L[u(z)]\mathrm{L}[j_v] = L[\mathrm{sint}] \qquad (2)$$

$$L[u(z)] = \frac{L[sint]}{\mathrm{L}[j_v]} \qquad (3)$$

Putting equation (5) and (6) in equation (3), we get

$$L[u(z)] = \frac{\frac{1}{p^2+1}}{\frac{w^v}{(z+\sqrt{p^2+w^2})\sqrt{p^2+w^2}}} \qquad (4)$$

The integral equation define above can be converted in to Gaussian plane and then the result can be getting in the form of Gaussian line integral along with some suitable path with the utilization of some quadrature rules. The solution formula recovered in this format is given as.

$$u(z) = 1/2\pi i \int_Q e^{p\tau} F(P)dp \qquad (5)$$

so we can use parabolic path which is suitable for any type of integral equation and also need less nodal points and getting good accuracy.

$$Q = W + \vartheta(1 - \sin(g - ip)) \qquad (6)$$

where W, ϑ, g are the parameters in equation (6)

For,

$$p = p(f), \qquad s_n = s(f_n), \qquad f_n = nk$$

So equation (12) in the form trapezoidal rule we get

$$u(z) = \sum_{-J}^{J} 1 \exp(Sjt)F(P)dp \qquad (7)$$

Table 2 : The approximate solution for the example 2 the results obtained by the present method when the quadrature points N=50 and oscillation parameter w=1000.

t	**0.1**	0.4	1
Uapp	99.83	$2.95e+002$	8.4147e+002
Uexct[2]	99.8341	2.9552e+002	8.41472e+002
Uapp[2]	99.8341	2.9955e+002	8.8144e+002
Error	0.0007	0.0000014	0.000005

5: Conclusion

In this paper, we consider the Volterra integral equation of oscillatory type kernel and whose right-hand side is any type of functions. The right-hand side of equations (1) will be approximated numerically in such a way that its Laplace transform can be computed in a very simple way. For this we ware incorporate the Least Square series approach, which is enable us to compute the Laplace transform in a very simple way. Then further, the inverse Laplace transform is to be approximated numerically by the developed scheme. The developed scheme is to be able to approximate the solution with better accuracy, and it can then be applicable to variety of Volterra integral equations with difference kernels.

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CURRENT PRACTICES IN ENERGY-EFFICIENT FACADE DESIGN: DOUBLE SKIN FACADE SYSTEMS AND PHASE CHANGE MATERIALS

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ABSTRACT

The growing concerns surrounding energy consumption, driven by factors such as the industrial revolution, rapid population growth, and the extensive exploitation of natural resources, have prompted global efforts to minimize reliance on non-renewable energy sources. Collaboration between nations has fostered the development of renewable alternatives. The construction industry, a significant player in energy consumption, faces the challenge of adapting to these changes, given its 35% contribution to overall energy usage. As a response, contemporary building design prioritizes energy efficiency, climate adaptability, and user comfort. The building "facade," serving as a crucial interface between the interior and the external environment, plays a pivotal role in optimizing energy use. Technological advancements and innovative construction systems now enable the design of energy-efficient buildings, employing strategies such as multi-layered facades and novel materials. Double skin facade systems have emerged as a popular choice, effectively controlling heat and light to enhance energy efficiency. Another noteworthy approach involves integrating Phase Change Materials (PCM) into building facades. PCM can absorb and release significant latent heat energy during phase transitions, contributing to energy storage and management. Both double skin facade systems and PCM applications prove versatile, applicable to new constructions as well as retrofits of existing buildings, offering improvements in overall energy consumption. This study delves into these energy-efficient systems through a comprehensive literature review. It elucidates the principles behind double skin facade systems and PCM, examining buildings where these systems are implemented individually or in combination, along with their resulting energy efficiencies. The ultimate goal is to enlighten stakeholders, fostering awareness about energy efficiency and contributing valuable insights to global energy development plans.

Keywords: Energy-efficient facade design, double-skin facade systems, phase change materials.

ENERJİ ETKİN CEPHE TASARIMINDA GÜNCEL UYGULAMALAR: ÇİFT KABUK CEPHE SİSTEMLERİ VE FAZ DEĞİŞTİREN MALZEMELER

ÖZET

Sanayi devrimi, hızlı nüfus artışı ve doğal kaynakların kontrolsüz kullanımının getirdiği enerji tüketimine dair endişeler; ülkelerin ortak iş birliği sonucunda yenilenemeyen enerji kaynakları kullanımını en aza indirme ve yenilenebilir enerji kaynaklarına yönelme yaklaşımlarını ortaya çıkarmıştır. Küresel düzeyde konunun önemli bir paydaşı olan inşaat sektörü de enerji tüketimine katkısı bakımından bu durumdan etkilenmektedir. Bina inşaatı faaliyetleri, enerji tüketiminde %35 gibi önemli bir paya sahip olduğundan günümüzde yapı tasarım yaklaşımı; enerji tüketimini azaltacak, değişen iklim koşullarına uyum gösterecek ve kullanıcıya uygun konforu sağlayabilecek şekilde yeniden yorumlanmaya başlanmıştır. Bu bağlamda yapıyı dış ortamdan ayıran kabuğu ‘cephe’, enerjinin etkin kullanılması konusunda önemli yapı bileşenlerinden biri haline gelmiştir.

Gelişen teknoloji ve yapım sistemleri ile cephe katmanlarının sayısının artırılması ve cephenin bu katmanlarda yenilikçi malzemeler kullanılarak üretilmesi gibi uygulamalarla yeni yapıların enerji etkin tasarlanması mümkün hale gelmiştir. Çift kabuk cephe sistemleri de bu bağlamda günümüzde sıklıkla kullanılan sistemlerdendir. Dış ortam ile yapı içi arasında bir arayüz görevi üstlenen bu tür cephe sistemleri, ısı ve ışığın kontrol edilmesi ile enerji etkinliği sağlamaktadır. Bu sistemlere ek olarak yapı cephesinde kullanılan, erime ve katılaşma sırasında büyük miktarda gizli ısı enerjisi emebilen veya gerektiğinde ısı enerjisini depolayabilen Faz Değiştiren Malzemeler (FDM)'in kullanılması da yapının ısıtma-soğutma yüklerinin azaltılabilmesini sağlayan, enerji etkin bir başka sistemdir. Bu iki sistem, yeni yapılarda kullanılabildiği gibi mevcut yapı stoğuna da uygulanarak yapıların enerji tüketiminde iyileşme sağlayabilmektedir. Enerji etkin cephe tasarımında güncel uygulamaların araştırıldığı bu çalışma kapsamında, çift kabuk cephe sistemleri ve faz değiştiren malzemelerin kullanıldığı sistemler literatür taraması ile incelenmiştir. Çalışmada, sistemlerin tekil ve bir arada yer aldığı yapılar ve enerji etkinliklerinin değerlendirildiği araştırmalar incelenmiştir. Çalışma ile paydaşların konu hakkında bilgilendirilmesi ve enerji etkinliğine dair farkındalığın artırılması ile küresel ölçekte hedeflenen enerji kalkınma planına katkı sağlanması amaçlanmıştır.

Anahtar Kelimeler: Enerji etkin cephe tasarımı, çift kabuk cephe sistemleri, faz değiştiren malzemeler.

Giriş

Eski çağlardan itibaren insanoğlu, etrafında bulunan doğal ve beşerî kaynakları, yaşamını en ideal şekilde idame ettirebilmek için kullanmış, kendisine içerisinde konforlu ve güvenli şekilde yaşayabileceği yapılar inşa etmeye çalışmıştır. Endüstri devrimiyle birlikte insanın yaşam seviyesini artırmayı sağlayan teknolojilerin gelişmesi, yapılı çevreyi oluşturmada yeni yöntemlere olanak vermiştir. Öte yandan dünya nüfusunun hızla artması, kullanılan doğal kaynakların tükenişi ve artan enerji maliyetleri yapı tasarımında yeni yaklaşımlara sebep olmuştur. Günümüzde önemli toplumsal sorunlardan biri olan küresel ısınma ve iklim değişikliği mimarlık pratiğini büyük ölçüde etkileyen konulardandır. Buna göre mimari tasarımda sürdürülebilir malzeme seçimi, yeşil bina tasarımı, dayanıklılık ve adaptasyon, su ve enerji verimliliği gibi parametreler öne çıkmaktadır [1].

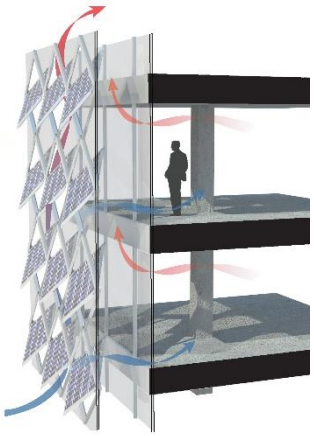
Binalar ve bina inşaat faaliyetleri küresel enerji tüketiminde %37, karbon emisyonunda ise %34 gibi bir paya sahiptir [2]. Bu sebeple, yeni tasarlanacak yapılarda ve mevcut yapılarda enerji etkinliğinin sağlanmasına yönelik strateji ve uygulamalar önem kazanmıştır.

Bir yapının enerji etkin olması; tasarımı, inşa edilmesi, işletilmesi, bakım/onarımı ve yıkımı gibi aşamaların tümünü içerecek biçimde enerji tüketiminin toplum ve birey faydası için azaltılmasıdır. Enerji etkin bir yapı, enerjiyi mümkün olan en az düzeyde tüketirken doğal kaynaklardan en fazla düzeyde istifade etmeli ve aynı zamanda kullanıcı konfor koşullarını (ısıl konfor, görsel konfor, akustik konfor ve iç hava kalitesi) karşılamalıdır [1].

Enerji etkin yapıların tasarlanmasında ilk aşamada yapının uygulanacağı sahanın seçimi, yapının yerleşimi, yapı formu ve mekânsal örgütlenmesinin uygun şekilde değerlendirilmesi gerekmektedir. Ardından yapı planı çözümlenirken kompakt bir yerleşim sağlanırken, iç mekanlar, mekanik hacimler ve doğal havalandırma kapsamında pencereler birlikte düşünülmelidir. Yapının dış ortam ile temas eden kabuğu "cephesi" de enerji etkinliğinin sağlanmasında önem taşımaktadır. Bu bağlamda uygun cephe çözümleri ve detaylarının yapıya entegre edilmesi, enerji etkin yapıya ulaşmaya yardımcı olmaktadır [3].

Enerji etkin bir yapı cephesi, enerji etkin cephe sistemleri ve enerji etkin akıllı malzemelerin kullanılması ile elde edilebilmektedir. Günümüzde yapılarda sıkça kullanılan enerji etkin cephe sistemleri; adaptif cephe sistemleri, fotovoltaik panel cepheler, düşey yeşil cepheler, medya cepheler, strüktürel membran cepheler ve çift kabuk cephe sistemleri olarak örneklendirilebilir (Şekil 1).

Strüktürel membran cepheler

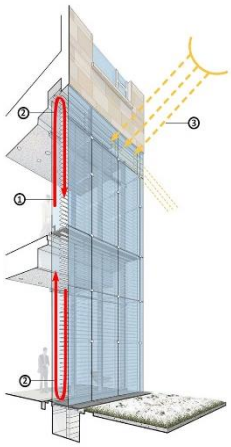


Adaptif cephe sistemleri

Fotovoltaik panel cepheler

Düşey yeşil cepheler

Medya cepheler



Çift kabuk cephe sistemleri

Şekil 1. Enerji etkin cephe sistemleri

Çift kabuk cephe sistemleri:

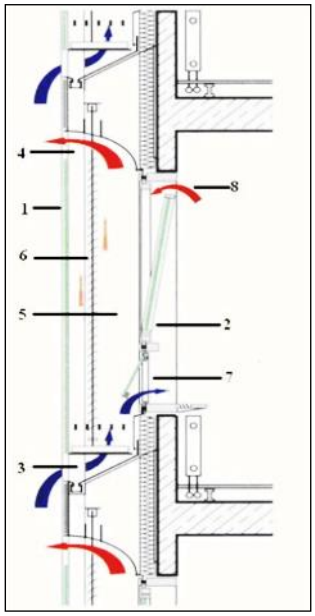
Enerji etkin cephe sistemlerinden çift kabuk cephe sistemleri, diğer tüm enerji etkin sistemlerle birlikte kullanılabilme imkanı ile günümüzde birçok yapıda farklı varyasyonları ile kullanılmaktadır.

Çift kabuk cephe sistemleri temelde dört ana elemandan oluşmaktadır [4]:

- Dış kabuk,
- İç kabuk (sabit veya açılabilen),
- Hava boşluğu/tampon bölge (20 cm ile 2 metre arasında değişen),
- Güneş kontrol elemanları (sabit veya hareketli).

Çift kabuk cephe sistemleri, dış ortamdan kaynaklanan gürültünün önlenmesine, ısı kazanç ve kayıplarını kontrol etmeye, doğal aydınlatma ve havalandırmaya imkan sağlayan sürdürülebilir bir sistemdir [4]. Çift kabuk cephe sisteminin örnek çalışma prensibi ve elemanlarının birbirleri ile ilişkisi Şekil 2'de verilmiştir.

Çift kabuk cephe sistemlerinde oluşturulan havalandırma boşluğu, iç ve dış mekân arasında bir tampon bölge oluşturmakta; aynı zamanda havalandırma sistemi ve bölümlendirme tipine göre kabuğun sınıflandırılmasına olanak vermektedir. Çift kabuk sistemler havalandırma sistemine göre üç, bölümlendirme tipine göre ise dört sınıfa ayrılmaktadır (Şekil 3). Bu sınıflandırma çeşitlerinden özellikle "bölümlendirme tipi", çift kabuk cephe sistemlerinin seçiminde önemli rol oynamaktadır.



Şekil 2. Çift kabuk cephe sistemi çalışma prensibi (1.dış kabuk, 2.sabit veya açılan iç kabuk, 3.dış ortamdan hava girişi, 4.dış ortama hava çıkışı, 5.hava boşluğu, 6.güneş kontrol elemanları, 7.iç ortama açılan alt pencere)

Çift Kabuk Cephe Sistemi Sınıflandırma	Havalandırma Modlarına Göre	Havalandırma Yöntemine Göre	Havalandırma Sistemine Göre	Bölümlendirme Tipine Göre
	• Hava boşaltma sistemi • Hava sağlama sistemi • Statik tampon bölge • Dış hava perdesi • İç hava perdesi	• Tampon sistem • Hava çekme sistemi • İkiz cephe sistemi • Birleşik (hibrit) sistem	• Doğal • Mekanik • Karma (hibrit)	• Kutu pencere tipi • Şaft tipi • Koridor tipi • Çok katlı

Şekil 3. Çift kabuk cephe sistemlerinin sınıflandırılması

Çift kabuk cephe sistemlerinde, iç ve dış kabuk arasındaki boşluk, yapının hangi elemanları arasında tanımlandığına göre tasarım ve performans açısından değişiklik göstermektedir. Bu cephe sistemlerinde bölümlendirme kutu pencere tipi, şaft tipi, koridor tipi (kat yüksekliğinde) ve çok katlı (bina yüksekliğinde) olmak üzere dört farklı şekilde sınıflandırılabilmektedir [4].

- Kutu pencere tipi çift kabuk cephe

Kutu pencere tipi çift kabuk cephelerde, iç ve dış kabuk arasındaki boşluk hem yatay hem de düşey olarak bölünmüş ve böylece birbirinden bağımsız birimlere ayrılmıştır (Şekil 4). Her bir kutu pencere, kendi taze hava girişi ve egzoz hava çıkışına sahiptir. Bu tip çift kabuk cepheler, dış ortam gürültüsünün fazla olduğu veya odadan odaya ses yalıtımının gerekli olduğu durumlarda uygulanmaktadır.

- Şaft tipi çift kabuk cephe

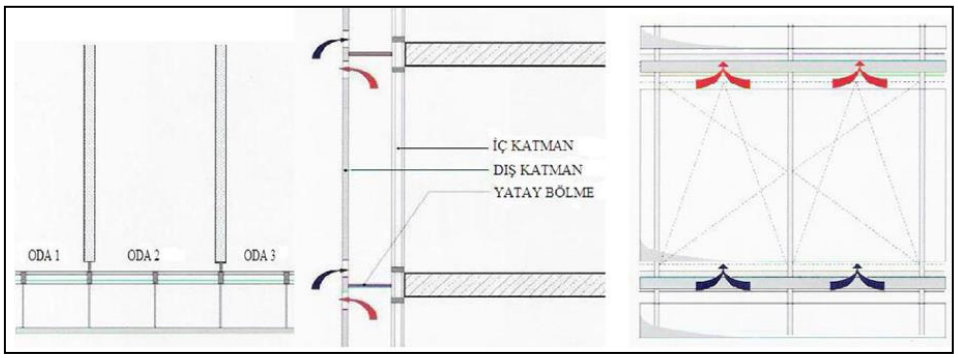
Şaft tipi çift kabuk cephe sistemlerinde, bina yüksekliği boyunca belirli akslar arasında devam eden ve bir baca gibi görev yapan şaftlar bulunmakta ve bu şaftlar kutu tipi cepheler ile birlikte çalışmaktadır. Şaftların her iki yanında bulunan kutu cephelerin altında yer alan kapaklardan şafta temiz hava girişi olmakta ve doğal havalandırma sağlanmaktadır. Şaftın içerisinde bulunan kirli hava ise baca etkisi ile yükselmekte ve şaftın tepe noktasında yer alan menfezler aracılığıyla dışarı atılmaktadır (Şekil 5) [5]. Diğer çift kabuk cephe tiplerine göre, şaft tipi cepheler yangın korunumu, gürültü denetimi, temiz ve kirli havanın karışması gibi konularda dezavantajlı konumdadır.

- Koridor tipi çift kabuk cephe

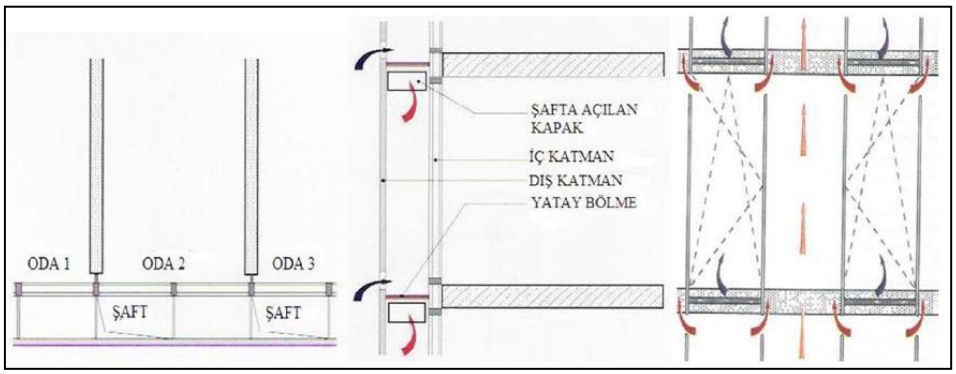
Koridor tipi çift kabuk cephe sistemleri içerisinde en çok kullanılan tiplerden biridir. Her kat için, birbiri üzerine denk gelecek şekilde yerleştirilmiş, taze havayı içeri ve kirli havayı dışarı iletecek menfezler bulunmaktadır. Kat döşemesinin altında yer alan menfezden içeri alınan hava ısınıp yükselmekte ve döşemenin üstündeki menfezden havalandırma boşluğuna iletilmektedir (Şekil 6) [5]. Yapı içerisinde ısı, ses, duman iletimi bu sistemle kontrol edilebilmekte ve yangının katlar arası geçişi de önlenebilmektedir.

- Çok katlı/Bina yüksekliğinde çift kabuk cephe

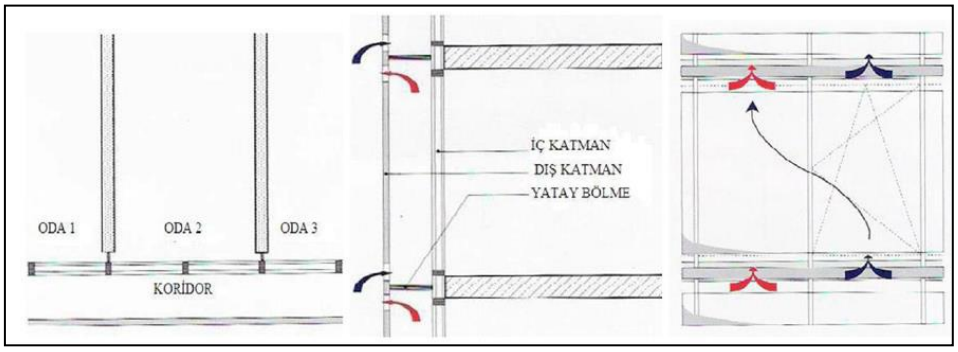
Çok katlı çift kabuk cephe sistemlerinde, iç ve dış kabuk arasında bulunan boşluk tüm katlar boyunca devam etmekte (bazen belirli aralıklarla bölünebilir) ve bir baca görevi görmektedir. Katlar arasında hava geçişini engellemeyecek ve temizliğe izin verecek şekilde tasarlanmış yürüme yolları bulunmaktadır. Bu tip cephelerde, cephenin altında yer alan menfezlerden içeri iletilen temiz hava ısınarak yükselmekte ve ardından cephenin en üst noktasından dışarı atılmaktadır (Şekil 7) [5]. Binanın ısıtıldığı dönemde bu menfezler kapatılarak cephenin bir sera görevi üstlenmesi sağlanabilmekte ve böylece güneş enerjisi ile binanın pasif şekilde ısıtılması sağlanabilmektedir.



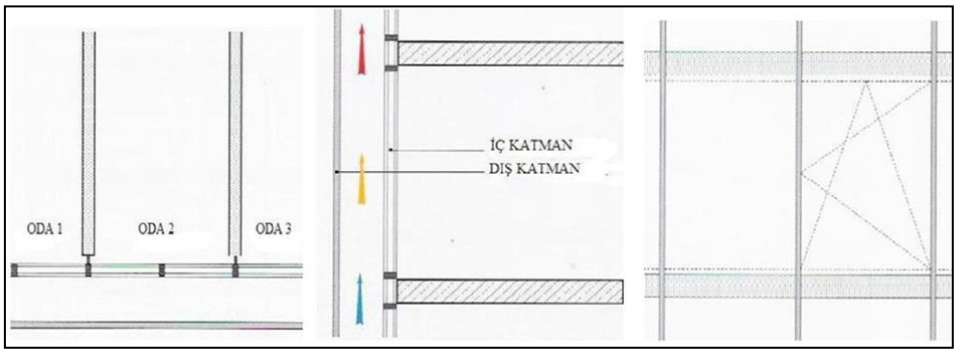
Şekil 4. Kutu pencere tipi çift kabuk cephe sistemi kısmi plan, kesit ve görünüş çizimleri



Şekil 5. Şaft tipi çift kabuk cephe sistemi kısmi plan, kesit ve görünüş çizimleri



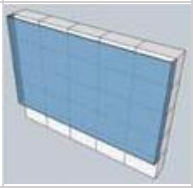
Şekil 6. Koridor tipi çift kabuk cephe sistemi kısmi plan, kesit ve görünüş çizimleri



Şekil 7. Çok katlı çift kabuk cephe sistemi kısmi plan, kesit ve görünüş çizimleri

Çift kabuk cephe sistemleri bölümlenme tiplerine göre kendi içinde avantaj ve dezavantajlara sahiptir. Bu özellikler Tablo 1'de verilmiştir. Buna göre yapının işlevine, yapıda kullanılan malzemelere, kullanıcı profiline ve iklimsel verilere göre uygun bölümlenme tipine sahip çift kabuk cephe sistemi seçimi yapılmalıdır.

Tablo 1. Çift kabuk cephe sistemlerin bölümlendirme tipine göre avantaj ve dezavantajları

Bölümlenme		Avantajlar	Dezavantajlar	Görünüm
Kutu pencere tipi	Yatay ve düşey bölüm	-Yangın ve ses yalıtımı -Koku geçişini önleme -Hızlı, seri üretim ve montaj -Her bölmenin kullanıcı tarafından ayrı kontrol imkanı -Kış aylarında ısı kazancı	-Uygun menfez tasarımı gerektirmesi -Düşük baca etkisine sahip olması	
Şaft tipi	Yatay ve düşey şaft	-Kuvvetli baca etkisi -Hava akımının az katlı yapılarda daha etkin -Şaft şeklindeki baca sistemi sayesinde etkin doğal havalandırma	-Düşük yangın ve ses yalıtımı -Gürültü kirliliği	
Koridor tipi	Yatay kat boyunca	-Yapıda aşırı ısınma olmaması -Her bölmenin döşeme alt ve üst hizasında havalandırma açıkları ile kendi içinde havalanması -Her katta yangın, duman ve ses kontrolü -Gölgeleme elemanlarının yerleşmesine uygun ara boşluk	-Düşük yangın ve ses yalıtımı -Düşük baca etkisi	
Çok katlı	Bölüm yok	-Kuvvetli baca etkisi -Yüksek ses yalıtımı -Gölgeleme elemanlarının yerleşmesine uygun ara boşluk -Ses izolasyonu için ek tabaka yerleşmesine uygun ara boşluk	-Yangın sırasında alevlerin sirayeti -Aşırı ısınma etkisi	

Enerji etkin cephe tasarımına ulaşmada kullanılan bir diğer strateji olan enerji etkin akıllı malzemeler ise çeşitli dış uyaranlara karşı (ısı, ışık, elektrik, sıcaklık değişimi, kuvvet vb.) kendilerine özgü farklı tepkiler gösterip özelliklerini değiştirerek veya enerjiyi dönüştürerek yapıya birtakım avantajlar sağlayabilmektedir (Tablo 2) [6]. Enerji etkin malzemelerden "faz değiştiren malzemeler" enerji etkinliğinin sağlanması amacıyla güncel uygulamalarda kullanılmakta ve enerji tasarrufunun ölçüldüğü deneysel çalışmalarda öne çıkmaktadır.

Tablo 2. Enerji etkin akıllı malzemelerin özellikleri ve sınıflandırılması [6]

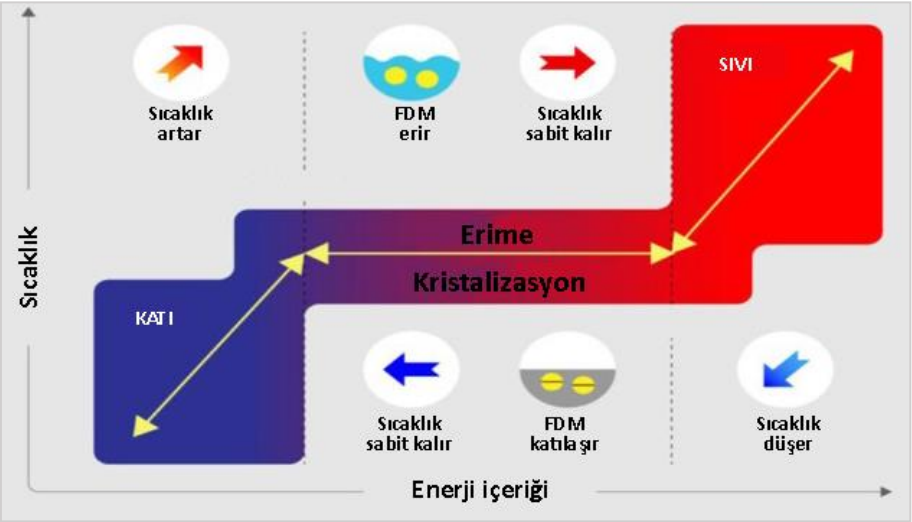
Akıllı malzeme türü	Akıllı malzeme grubu	Dış uyaran
Özellik değiştiren akıllı malzemeler	Foto-kromik malzeme	Işık
	Termo-kromik cam	Isı
	Elektro-kromik cam	Elektrik
	Fotokatalitik malzeme	Işık
	Faz değiştiren malzeme	Sıcaklık farkı
Enerjiyi dönüştüren akıllı malzemeler	Foto-elektrik malzeme	Işık (Işık enerjisi)
	Piezoelektrik malzeme	Kuvvet (Mekanik enerji)
	Piroelektrik malzeme	Isı (Isı enerjisi)
	Termoelektrik malzeme	Malzeme yüzeyleri arası sıcaklık farkı
	Kemoelektrik malzeme	Kimyasal ortam
	Elektrominesans malzeme	Elektrik

Faz değiştiren malzemeler:

Yeni nesil enerji depolama malzemeleri olan faz değiştiren maddeler (FDM'ler), ısıl enerjinin gizli ısı olarak depolanmasına imkan tanımaktadır. Bu malzemeler, sıvı fazdan katı faza veya katı fazdan sıvı faza geçiş sırasında büyük miktarda ısının depolanmasına veya salınmasına olanak sağlamaktadırlar. FDM'lerin belirli bir hacimde tutulabilmesi için faz değişimi sırasında makro veya mikro/nano ölçekte kapsüllenmeleri gereklidir (Şekil 8). Kapsülleme işlemi, malzemenin dış etkenlerden az etkilenmesini sağlar, aynı zamanda malzemenin katıdan sıvıya geçişinde kabuk hacminin sabit tutulmasını ve ısı transfer yüzeyinin artmasını mümkün kılmaktadır [7].

Şekil 8. Kapsüllenmiş FDM'ler

Faz değiştiren malzemeler yapıların enerji etkinliğini sağlamak amacıyla duvarlarda, tavan/çatılarda, zeminde, pencere ve kapılarda, ısıtma, havalandırma ve klima sistemlerinde, yalıtım malzemeleri ile birlikte kullanılabilmektedir. FDM'lerin çalışma prensibi Şekil 8'de görüldüğü gibi malzemenin katı-sıvı faz değişimi sırasında ısıl enerji depolaması ve bulunduğu iç mekanın sıcaklığının sabit kalması şeklindedir.



Şekil 9. FDM'lerin çalışma prensibi ([8]'den uyarlanmıştır)

FDM'ler organik ve inorganik olmak üzere iki grup malzemeden oluşabilmektedir. Organik FDM'ler parafinler (C_nH_{2n+2}), yağ asitleri, şeker alkoller ve Bio-FDM'ler olarak sıralanabilir. Tuz hidratlar ve metalikler ise inorganik FDM'lere örnek olarak verilebilmektedir. Parafinler ve tuz hidratlar, yapılarda en sık kullanılan FDM'lerdendir.

Tablo 3. FDM'lerin avantajları, dezavantajları ve faz değişim sıcaklık aralıkları

FDM türü	Avantajları	Dezavantajları	Faz değişim sıcaklık aralığı
Organik FDM	• Aşındırıcı değil • Kimyasal dayanımı iyi • Yapı malzemeleri ile kullanıma uygun • Düşük buhar basıncı • Yüksek gizli ısıya sahip	• Düşük ısı iletkenlik • Faz değişimi esnasında oluşan hacimsel değişim • Yanıcılık	19-28 °C
İnorganik FDM	• Yüksek gizli ısıya sahip • Yüksek ısıl iletkenlik • Ekonomik • Yanıcı değil	• Metallerle birlikte kullanıldığında aşındırıcı • Ayrışabilir	25-35 °C

Materyal ve Metot

Enerji etkin cephe sistemleri ve akıllı malzemelerin yapılara uygulanması ile enerji etkin yapı yaklaşımına katkı sağlayan üç farklı yapı örneği literatür çalışmalarıyla incelenmek üzere çalışmanın materyali olarak belirlenerek Tablo 4'te verilmiştir.

Tablo 4. Çalışmanın materyalini oluşturan yapı örnekleri

#	Yapı Adı	Konumu
1	Sapphire İstanbul Alışveriş Merkezi	İstanbul, TÜRKİYE
2	Yüzen Pavilyon	Rotterdam, HOLLANDA
3	Soongsil Üniversitesi A Binası	Seoul, GÜNEY KORE

Çalışmanın metodu dört aşamadan oluşmaktadır. Birinci aşamada, enerji etkin cephe sistemlerinden 'Çift Kabuk Cephe Sistemleri' ve enerji etkin akıllı malzemelerden 'Faz Değiştiren Malzemeler' hakkında ilgili yerli ve yabancı literatür taraması yapılmıştır. İkinci aşamada, enerji etkin cephe sistemleri ve akıllı malzemelerin yapılara uygulanması kriterini sağlayan üç farklı yapı örneği literatür analizi üzerinden seçilmiştir. Üçüncü aşamada, seçilen yapı örnekleri; konumu, bulunduğu iklim bölgesi, tasarımcısı, yapım yılı, işlevi, büyüklüğü ve taşıyıcı sistem türü gibi nitelikler bakımından incelenerek analiz edilmiş ve künyeleri verilmiştir. Ardından bahsi geçen yapılara entegre edilmiş enerji etkin stratejiler de ortaya konulmuştur. Son aşamada, tüm veriler ve analizlerden yola çıkılarak enerji etkin cephe sistemleri ve akıllı malzemelerin yapılarda enerji etkinliğinin sağlanmasında kullanılması ile ilgili bir senteze varılmıştır.

Bulgular

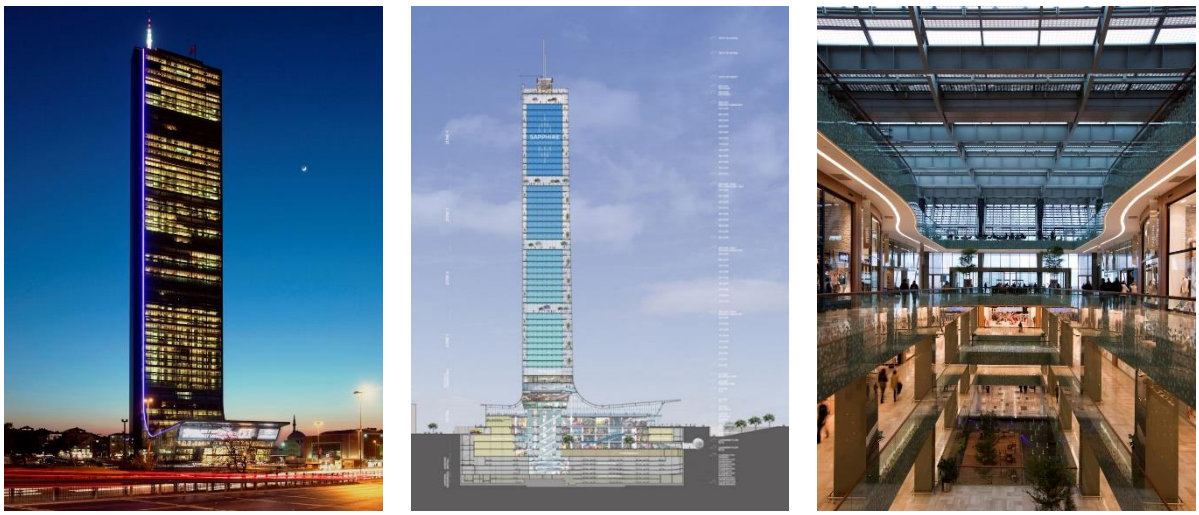
Çalışmanın bu bölümünde, enerji etkin cephe tasarımı prensibi ile inşa edilmiş ve enerji etkin iyileştirilmiş yapı örnekleri incelenmiştir. İncelenen yapılara ait bilgiler Tablo 5'te verilmiştir.

Tablo 5. İncelenen yapıların künyeleri

Yapı ismi	Sapphire İstanbul AVM	Yüzen Pavilyon	Soongsil Üniversitesi A Binası
Konum	İstanbul/TÜRKİYE	Rotterdam/HOLLANDA	Seoul/GÜNEY KORE
İşlev	Karma (Ticari+konut)	Karma (Konferans+sergi)	Eğitim
Alan	165.139 m²	1000 m²	3993 m²
Tasarım	Tabanlıoğlu Mimarlık	deltasync & Public Domain Architecten	belirtilmemiş
Yapım yılı	2011	2010	belirtilmemiş
Taşıyıcı sistem	Betonarme+çelik	Betonarme+çelik	Betonarme
İklim	Akdeniz Nemli subtropikal Okyanusal	Ilıman Okyanusal	Subtropikal Karasal

Sapphire İstanbul:

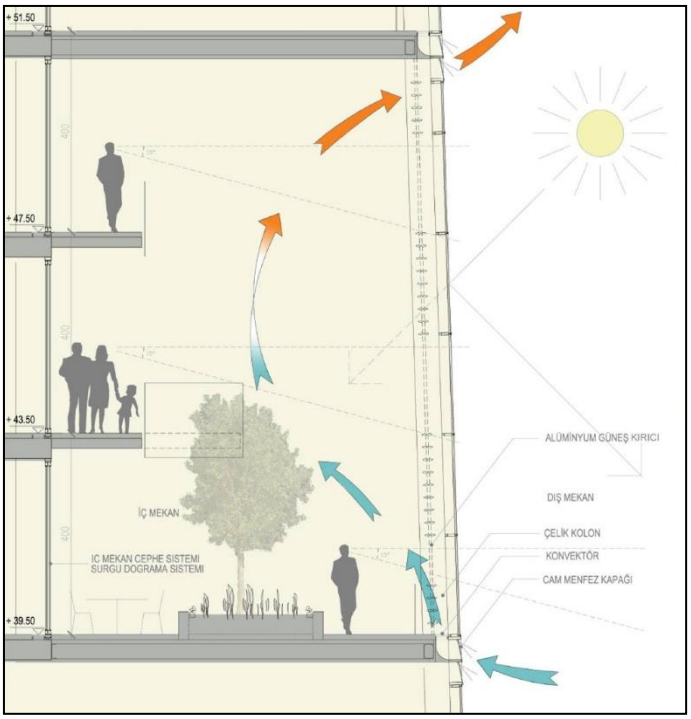
Betonarme ve çelik taşıyıcı sistem kurgusuna, karma işleve sahip yapının inşası, 2011 yılında Tabanlıoğlu Mimarlık tarafından tamamlanmıştır. Yapının zemini altında bulunan on katın altısı otopark, dördü alışveriş merkezi olarak kullanılmaktadır. Zemin üstü kotlarda ise 120 m²'den 1100 m²'ye kadar değişen 177 adet konut yer almaktadır (Şekil 10) [9].



Şekil 10. Sapphire İstanbul AVM (solda dış cephe, ortada kesit, sağda AVM alanı)

Bina cephesi birbirinden bağımsız iki kabuktan oluşmakta; iç mekanlar, dışta oluşturulan kabuk yardımı ile olumsuz meteorolojik koşullardan ve sesten korunmaktadır. Bu kabuk sistemi her 3 katta bir gökyüzü bahçesi olarak tariflenen alanlar oluşturmaktadır. Oluşturulan şeffaf kabuk aynı zamanda iç mekan-dış atmosfer arasında tampon bölge görevi görmekte, yapı fiziği çözümlerini pozitif yönde etkilemektedir. Kat boyu devam eden kabuk, çift kabuk cephe sistemlerinden kat yüksekliğinde/koridor tipi sınıfına dahil olmaktadır (Şekil 11). Oluşturulan çift kabuk cephe sistemi ile nefes alabilen bina, iklimlendirme için daha az enerji tüketmektedir (Şekil 12) [9].

Şekil 11. Sapphire İstanbul üç katta devam eden gökyüzü bahçesi konsepti

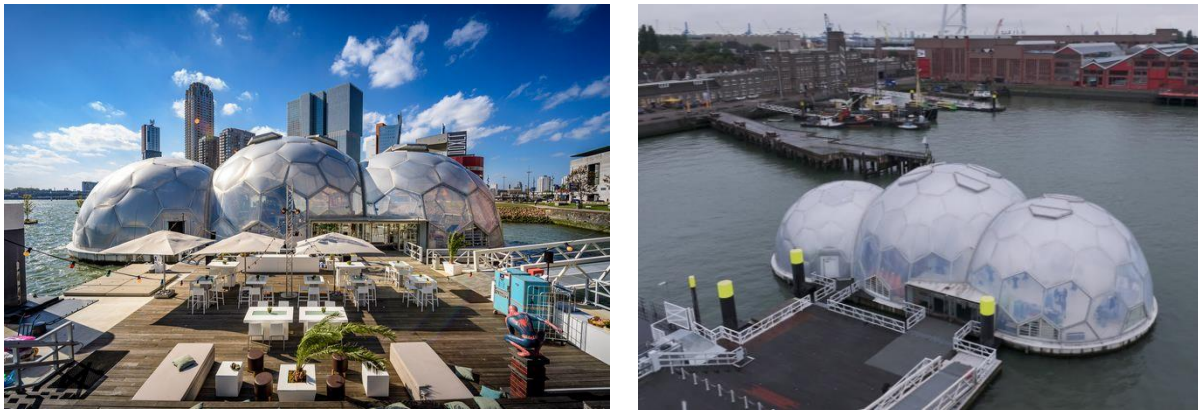


Şekil 12. Sapphire İstanbul çift kabuk cephe sistemi çalışma prensibi

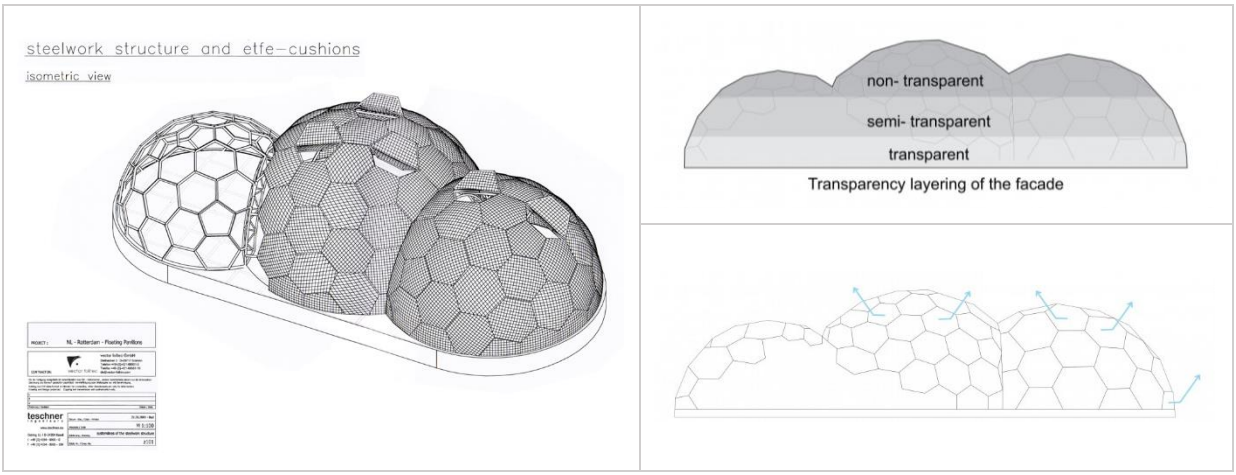
Yüzen Pavilyon:

Yüzen Pavilyon, Rotterdam'ın Rjinhaven nehri üzerinde kurulması planlanan enerji etkin yüzen yapılar için bir prototip niteliğindedir. Betonarme taban ve çelik kubbe strüktürüne sahip karma işlevli yapı, 2010 yılında deltasync & Public Domain Architecten tarafından tamamlanmıştır. En büyüğü 12 metre yarıçapa sahip olan

birbirine bağlı üç küreden oluşmaktadır. Pavilyonun temelleri beton kirişlerden oluşan bir ızgarayla birleştirilmiş 2,5 m'lik genişletilmiş polistiren (EPS) tabakasından oluşmakta ve dairesel formdadır. Yapı kubbesinde cam yerine camdan 100 kat daha hafif olan ETFE malzeme kullanılmış ve kubbenin bazı kapakları doğal havalandırma amacıyla açılabilmektedir. Ayrıca ETFE malzemenin aşağı kottan yukarı kota doğru opaklaşması da güneş ışınlarının olumsuz etkilerinden korunmada rol oynamaktadır (Şekjl 13-14) [10].

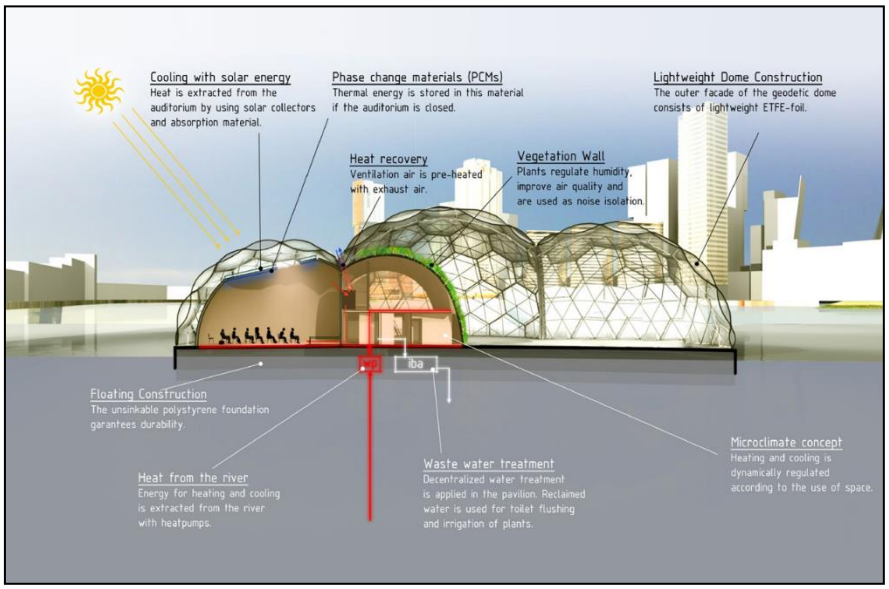


Şekil 13. Yüzen pavilyon



Şekil 14. Yüzen pavilyon açılabilen havalandırma kapakları ve kubbenin üst kota doğru opaklaşması

Yüzen Pavilyon doğal havalandırma kullanımı, atık suların değerlendirilmesi, nehrin ısısından yararlanılması, güneş enerjisi ile soğutma enerjisi temini gibi sürdürülebilir stratejiye sahiptir. Ayrıca bünyesinde bulunan oditoryumun duvarları, enerjiyi depolayabilen ve serbest bırakabilen, yüksek ısı depolama kapasitesine sahip 21°C altında katı, üstünde sıvı özellik gösteren organik FDM'ler ile kaplıdır. Organik FDM'lerin kullanımı, aktif soğutmaya ihtiyaç duymadan oditoryumu belirli bir sıcaklığa kadar soğuk tutan bir termal tampon oluşturmaktadır (Şekil 15) [10].



Şekil 15. Yüzen pavilyon sürdürülebilir tasarım konsepti

Soongsil Üniversitesi A Binası:

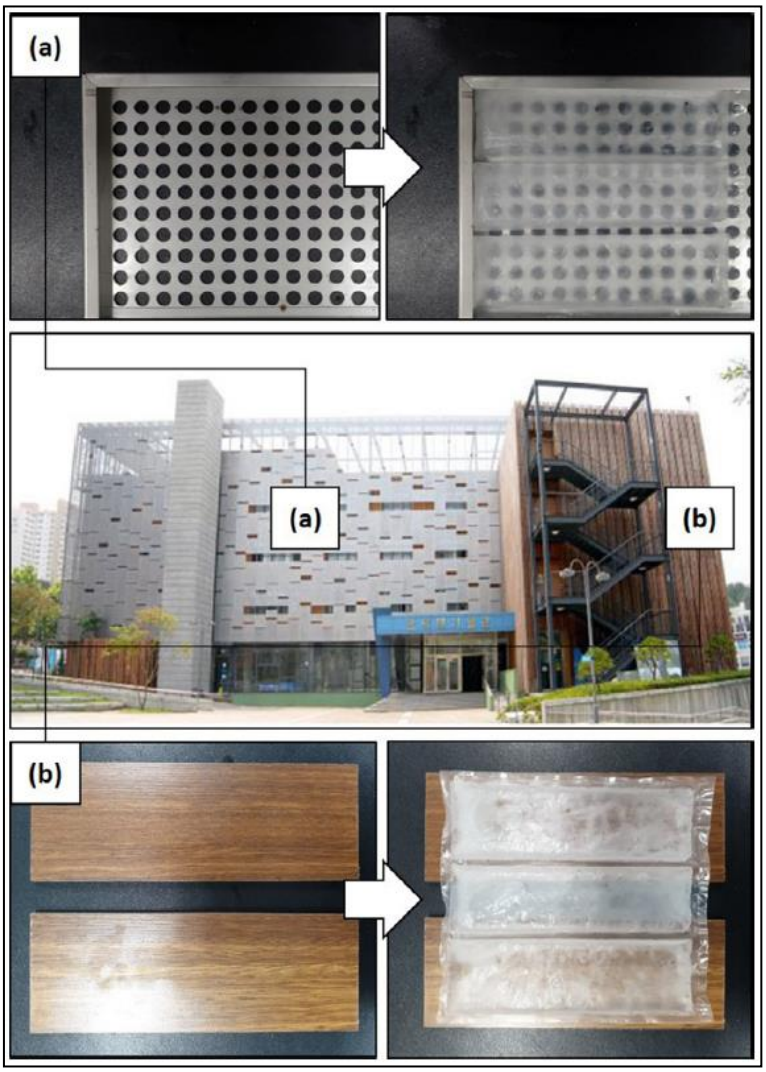
Park ve diğerleri (2020) çalışmalarında Seoul, Güney Kore'de yer alan dört katlı eğitim yapısında, yaz aylarında artan soğutma yüklerinin azaltılması için ikinci bir kabuk cephe ile güneş kontrol elemanları eklemiş, ardından bu sisteme faz değiştiren malzemeler entegre edilerek enerji etkinliği incelemişlerdir [11].

Şekil 16. Soongsil Üniversitesi A Binası enerji etkin iyileştirme süreci

Güney Kore'de, kışın Sibirya'dan gelen karasal atmosfer basıncı nedeniyle soğuk ve kurak, yazın ise Kuzey Pasifik'ten gelen deniz atmosferi basıncı nedeniyle sıcak ve nemli iklim görülmektedir. Yaz aylarındaki soğutma yüklerinin azaltılması için cephede gölgeleme elemanı ile iyileştirme yapılırken, kış aylarındaki ısıtma yükü de düşünülerek bu gölgeleme elemanına Faz Değiştiren Malzemeler eklenmiştir (Şekil 17). Cephede kullanılan organik parafin FDM'ler ve ısıl özellikleri Tablo 6'da verilmiştir.

Tablo 6. Çalışmada kullanılan organik parafin FDM elemanların ısıl özellikleri [11]

Isıl Özellikler		**Oktadekan (C18H38)**	**İkosan (C20H42)**	**Dokosan (C22H46)**
Erime sıcaklığı	Isınma (°C)	26.11	35.64	43.15
	Soğuma (°C)	25.05	33.63	42.21
Gizli ısı kapasitesi (J/g)	Isınma	256.5	189.0	241.3
	Soğuma	245.8	180.5	234.2

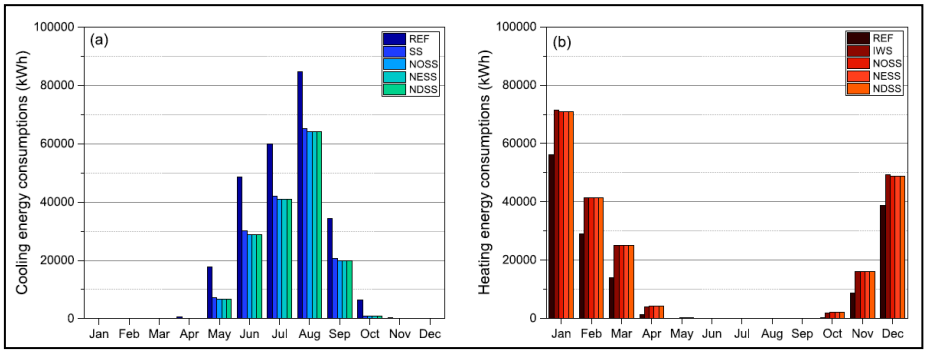


Şekil 17. İyileştirmede kullanılan FDM'lerin cephede uygulanması [11]

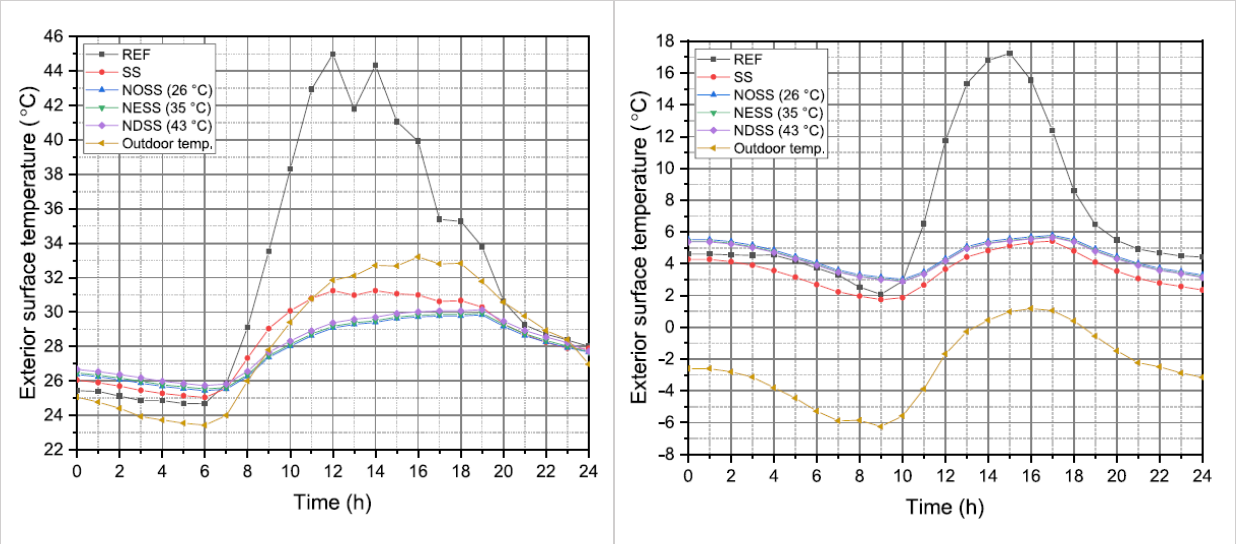
İncelenen çalışmada, oluşturulan gölgeleme elemanı ve FDM kullanımının enerji tüketimine etkisinin ölçülmesi amacıyla aşağıda sıralanan analizler geçekleştirilmiştir:

- Soğutma ve ısıtma dönemi enerji tüketimi (Şekil 18),
- Yaz ve kış ayları için gölgeleme elemanı maksimum yüzey sıcaklığı (Şekil 19),

- Yatırım, enerji tüketimi, yıllık tasarruf ve geri-ödeme süresi (Tablo 7).
-



Şekil 18. Gölgeleme elemanına göre yapının enerji tüketimi (soğutma enerjisi-solda, ısıtma enerjisi-sağda) [11]



Şekil 19. Dış yüzey sıcaklığı-dış ortam sıcaklığı ilişkisi (yaz-solda, kış-sağda) [11]

Tablo 7. Çalışmada ortaya konulan Yatırım, enerji tüketimi, yıllık tasarruf ve geri-ödeme süresi [11]

Gölgeleme opsiyonları	İlave yatırım	Enerji maliyeti (USD/yıl)	Yıllık kazanç (USD/yıl)	Basit geri ödeme süresi (yıl)
İlk durum	-	31,778.58	-	-
Gölgeleme elemanı	81,355.93	29,591.55	2187.03	37.19
Gölgeleme elemanı + FDM	91,514.81	29,142.78	2635.80	34.72

Çalışmanın incelenmesi sonucunda elde edilen bulgular aşağıdaki gibidir:

- Yalnızca gölgeleme elemanı kullanımı ile soğutma enerjisi %44 oranında azalmıştır ancak kış aylarındaki ısıtma döneminde enerji tüketimi artmıştır. Gölgeleme elemanlarının FDM ile birlikte kullanılması da yaz döneminde enerji tüketimini bir seviye daha azaltırken, kış döneminde ise yalnızca gölgeleme elemanının olduğu duruma göre enerji tüketimi azalmıştır (Şekil 18).
- FDM kullanımı, yapı malzemelerindeki faz farkı etkisiyle gün içerisindeki sıcaklık dalgalanmalarının yapıya etkisini önlemektedir. Bu sebeple iç mekanda ani sıcaklık dalgalanmalarının oluşması engellenmektedir. Ancak ısıtma döneminde bu durum dış ortam sıcaklığından faydalanmayı azaltmaktadır (Şekil 19).

- Maliyet ile ilgili analizler incelendiğinde, FDM'li gölgeleme sisteminin yatırım maliyeti yüksek olmasına rağmen, geri ödeme süresinin yaklaşık 3 yıl kısalmaktadır. Ayrıca yatırım sonrası enerji maliyetleri il duruma göre yaklaşık %8 oranında azalmıştır. Sonuç olarak, yapıda FDM ve gölgeleme sisteminin birlikte kullanılması (ısıtma dönemindeki enerji tüketiminin artmasına rağmen) hem enerji tüketimi hem maliyet açısından avantajlıdır (Tablo 7).

Sonuç ve Öneriler

Küresel düzeyde inşaat faaliyetleri ve mevcut yapıların kullanımı, dünya enerji tüketiminin %37'sini oluşturmaktadır. Bu durum mimari tasarımda enerji tüketimini önemli bir girdi haline getirmiştir. Söz konusu enerji tüketiminin azaltılması, yapıların cephelerinin enerji etkin bir yaklaşımla tasarlanması ile mümkün olabilmektedir. Yapı cephesinin bu anlayış ile tasarlanması, enerji etkin cephe sistemlerinin ve akıllı malzemelerin kullanılması ile elde edilebilmektedir.

Çalışmada incelenen yapılarda, çift kabuk cephe sistemi ve FDM'lerin kullanımı; daha sürdürülebilir, ekolojik ve daha az enerji tüketen yapılar elde etme yolunda birer örnek niteliğindedir. Sapphire İstanbul'da çift kabuk cephe sistemi kullanımı ile yüksek ve saydamlık oranı fazla olan bir yapıda doğal havalandırma ve ısıl kazançların kontrolü sağlanmıştır. Diğer yandan Yüzen Pavilyon'da doğal havalandırma ve oditoryum duvarlarında kullanılan organik FDM'ler ile yapıdaki sıcaklık düzeyi optimum düzeyde tutulabilmiştir. Soongsil Üniversitesi A Binası'nda ise mevcut bir yapıya çift kabuk cephe sistemi ve faz değiştiren organik parafin malzemelerin uygulanması ile özellikle yaz aylarında soğutma için tüketilen enerji miktarında önemli oranda azalma görülmüştür. Ancak aynı azalmanın kış dönemi ısıtma enerjisi tüketiminde görülmemesi, uygulanan yöntemin yapının bulunduğu coğrafya ve iklim için yetersiz kaldığını göstermektedir. Bu sebeple söz konusu iklim özelliklerine sahip bir coğrafyada yer alan yapılar için, ısıtma dönemine yönelik farklı stratejilerin uygulanması gerektiği anlaşılmaktadır.

Çalışma sonucunda elde edilen verilere göre enerji etkin cepheler tasarlanırken yapının işlevi, konumu, güneşlenme durumu, iklimsel veriler gibi daha da genişletilebilecek parametreler incelenerek kullanılacak stratejilere karar verilmelidir. Bu parametrelerin incelenmediği veya yanlış yorumlandığı durumlarda, yapılan tasarım ve iyileştirme müdahaleleri doğru sonuçlar vermeyebilir. Buna ek olarak bu müdahalelerin sonucunda yüksek maliyetlerle karşılaşılabilmektedir. Doğru kurgulanan enerji etkin bir cephe sistemi ile, yıllık ısıtma ve soğutma enerji tüketimi azaltılarak küresel enerji tüketimi azaltma hedeflerine katkı sağlanacağı düşünülmektedir.

Çalışmada incelenen yapı ve enerji etkin uygulamaların benzerlerinin sayı ve niteliklerinin artması ile, konu hakkında farkındalık düzeyinin artacağı ve enerji tüketiminde küresel düzeyde erişilmek istenilen hedeflere bir adım daha yaklaşılacağı düşünülmektedir. Bu çalışmayı takiben, iklim değişikliği ile mücadelede mimarlık disiplininin yeri ve öneminin anlaşılması, yapılarda enerjinin etkin kullanılması, enerji etkin sistemlerin mimarlığın her aşamasında göz önünde bulundurulması ve buna yönelik mesleki stratejiler geliştirilmesi, ilgili kuruluşlar tarafından bahsi geçen konularda eylem planlarının oluşturulması gibi konuların, gelecek çalışmalarda ortaya konulması büyük önem arz etmektedir.

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LITERATURE REVIEW ON AIR TIGHTNESS PARAMETER IN BUILDING ENVELOPE

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ABSTRACT

Today, the climate crisis caused by the increase in energy consumption due to the rapidly growing population and industrialization keeps the issue of efficient use of energy on the agenda of all countries of the world. Energy is used intensively at every moment of the life cycle of buildings, from the construction phase to the demolition phase; Therefore, the construction sector is one of the most effective sectors in energy consumption. During the use of the building, energy is consumed to ensure indoor comfort conditions. The building envelope, which acts as a boundary between the interior and exterior environment, directly affects energy consumption, indoor comfort conditions and user health. In terms of building physics, possible problems in the building envelope appear in the form of moisture transfer, thermal bridges and air leaks. Uncontrolled airtightness, defined as air passage between the indoor and outdoor environment, is based on the pressure difference created by the indoor-outdoor temperature difference. Leaks in the building envelope negatively affect building biology as well as energy efficiency and user health. Airtightness plays a decisive role in both uncontrolled heat loss and gain, as well as noise from the external environment and the entry of particles harmful to human health into the indoor environment. In this study, studies on building envelope sealing over a 20-year period were examined and comparative evaluations were made regarding the results. In addition, the regions in which the studies on building envelope sealing, which has a significant impact on energy consumption and user health, were carried out and the frequency of the studies were stated statistically.

Keywords: Airtightness, BlowerDoor Test, Building envelope, Energy efficiency, Comfort conditions.

1.Introduction

The building sector has a significant impact on the efficient use of energy and the consumption of natural resources worldwide. The life cycle of a building consists of construction, utilisation and demolition phases. While most of the energy used in the building sector is consumed in the construction process, which is the first of these phases, a significant amount of energy is consumed to provide user comfort parameters in the utilisation phase, which is the longest process of the life cycle of the building. Providing indoor comfort conditions is directly proportional to the improvement of indoor air quality. In addition, the improvement of indoor air quality is also important for user health. The comfort conditions provided by ventilation can be done mechanically or naturally in a controlled manner. However, as a result of the pressure difference in the building envelope, air leaks out of control also occur. Building envelope air tightness, which is the determining factor in inward or outward airtightness on the building facade, can be defined as resistance to air flow through the building envelope (Ji, 2017). Airtightnesss occurring in the building envelope can be associated with three basic elements: building typology, external climatic data and the interaction of the building with its environment (Eskola, 2007).

Air leaks in the building envelope are mostly caused by gaps in the building elements and problems in the building envelope. The joints of walls and floors, the junction of windows/doors and walls, and/or the passage of air through the building envelope following the points where electrical/mechanical installation pipes pass are considered as air leaks. Air leaks in the building envelope can increase energy consumption by affecting the heat transfer rate and ventilation. A study conducted in the USA supports this by reporting that airtightness in the building envelope increases the heating load of the building by 30-40% and the cooling load by 10-15%

in houses with lightweight skeleton carrier system (Emmerich, 2005). Airtightnesss affect the structural strength, thermal/humidity performance, indoor air quality, as well as user health, comfort and safety in terms of noise control and fire safety (Sular, 2006). Today, as a result of increasing technological developments, noise sources are also increasing. In this case, noise problems may occur indoors as a result of not taking the necessary measures in terms of air leaks in the building envelope. It is stated that noise control can be achieved by preventing air leaks from the gaps between the frame and the wall outside the glass on transparent surfaces (Alemdag, 2011).

Since ensuring energy efficiency in buildings is one of the priorities in the energy programmes of developed countries, the importance and impact of energy efficient and low energy building design criteria in the building sector is increasing (Gürgün, 2017). Air leaks, which are effective in providing comfort conditions at the highest level with minimum energy cost in energy efficient buildings, can be measured by leakage tests and these tests are a requirement for energy efficiency and energy certification in many countries (Truong, 2017).

This comprehensive literature review examines building envelope airtightness performance and its effects on energy performance in buildings. The aim is to draw attention to airtightness as a building envelope problem and to emphasise the importance of building envelope airtightness for efficient use of energy. This study differs from other studies in the literature in terms of examining building envelope airtightness performance in detail and is important in terms of paving the way for new studies on this subject.

1.1. Airtightness

The purpose of ensuring air tightness in the building envelope is to increase the energy performance of the building, to prevent building damage due to condensation and to maintain indoor air quality (URL - 1).

The flow of air into the indoor environment through cracks, unwanted openings or passages formed during the use of external doors and windows in the building envelope, which acts as a wall between the external environment and the internal environment in buildings, can be defined as airtightness (infiltration), and the flow of air in the indoor environment to the external environment through openings can be defined as airtightness (exfiltration) or airtightness (Lohmeyer, 1985). The air pressure difference between the indoor and outdoor environment determines the direction of the air flow in the building envelope. If the outdoor air pressure is high (positive pressure), infiltration occurs, and if the indoor air pressure is high (negative pressure), exfiltration occurs (ASTM, 2015). The simplest definition of airtightness is the average air volume passing through the 1 m^2 surface of the building envelope at a pressure difference of 50 Pa across the building envelope (Dorer, 2004). In buildings, airtightness occurs through capillary gaps in materials, joints of windows/doors with walls, joints of different structural elements and joints with mechanical and electrical installation equipment. Approximately 20-50% of heat losses in buildings are caused by air leaks (URL - 1). The quality of workmanship in applications, the joints of different material units and the areas where mechanical and electrical installations overlap are important factors affecting the air tightness capacity (Taylor, 2013).

1.2. Airtightness Measurement Methods

Air infiltration in the building envelope can be detected by visual inspection, the use of measuring instruments and computer simulations. By means of measurement techniques, areas causing airtightness in existing buildings can be identified and repaired or renewed. In buildings in the design stage, computer simulation programmes are used to enable arrangements to improve the building envelope sealing performance. As a result of examining the building envelope and detecting damages in the building envelope before airtightness measurements are made comments can be made about the air tightness status (TS EN 13829, 2001).Air tightness measurements are performed by BlowerDoor Test (BDT) method and Pulse Test methods shown in Figure 1.

Figure 1. CBT and Pulse Test device (URL - 2, URL - 3).

2.Method

Within the scope of the study, a systematic literature review was conducted on the concepts of "airtightness", "energy efficiency" and "building envelope" in order to draw attention to air leaks, which are among the building envelope problems. Resources were scanned by searching in different categories using Sciencedirect, ResearchGate and Google Scholar databases. During the literature review, limitations were placed on the topics covered by the main headings in order to determine which sources would be evaluated in the study. Research on air tightness; Studies examining i) definition of airtightness, ii) building envelope airtightness performance, iii) airtightness - energy relationship and iv) airtightness measurements were examined. Despite their importance, this research aims to overcome such limitations of previous studies by providing an in-depth understanding of the effects of airtightness on energy consumption and human health. Due to the scope of the study area, the resulting literature is analyzed analytically, its purpose and scope are determined, and relevant candidate articles are separated within the scope of this review. Therefore, the exclusion criteria were: i) out-of-scope articles, ii) articles related to airtightness outside the building envelope. The filtered articles are divided into three parts: literature review, measurement and simulation. These studies were then classified as "Airtightness on Building Envelope" and "Relationship Between Energy and Airtightness", as seen in Figure 1.

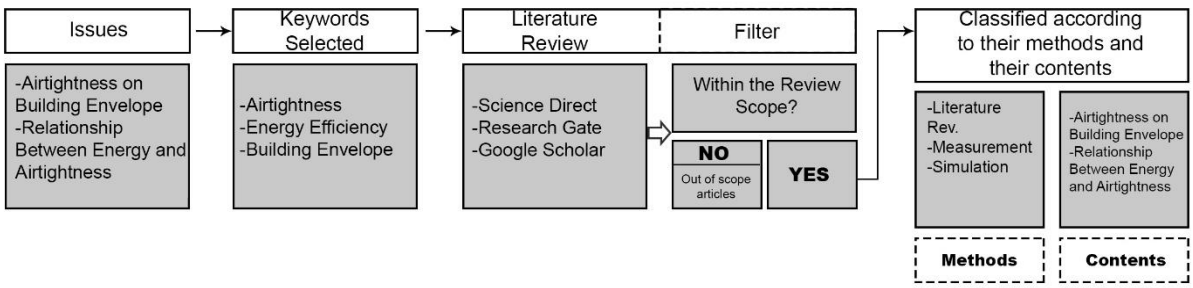

Figure 2. Work flow.

3.Airtightness Performance of Building Envelope

Building envelope air leaks directly affect indoor thermal comfort and energy consumption. Considering that the construction sector accounts for more than 40% of CO_2 emissions on a global scale, eliminating problems in the building envelope cannot be ignored to reduce energy consumption (Xu, 2023). Airtightnesss cause an increase in indoor heating and cooling loads. Since the indoor space is cooled due to airtightness during heating periods, especially in cold climates, air leaks increase the energy load of buildings for heating. A significant proportion of energy losses can be prevented by reducing airtightness in the building envelope, thus reducing

the demand for heating and cooling energy by 9 to 36% (Garrat, 1991). It is also reported that air tightness is responsible for 25% of the heating load and 4% of the cooling load in new buildings (Zeller, 1993).

While energy consumption in buildings with thermal insulation and airtight envelope is 60 kWh/m^2.year, this value is 10 kWh/m2.year in buildings with airtight passive house standard. Buildings constructed with adequate thermal insulation and airtight building arrangements can provide a comfortable indoor environment at sub-zero temperatures (Bekboliev, 2015). In a study conducted in Germany, the airtightness level of 48 low-energy buildings was measured and it was found that most of them had an n50 value greater than 3 (1/s). It is reported that mechanical ventilation cannot be used efficiently if the air exchange rate value is greater than 3 (Zeller, 1993).

Airtightness Mechanism and Factors in Buildings;

Airtightness mechanism occurs when air movements acting on the building envelope create positive and negative pressure areas on the facades of the building. Air leaks are basically caused by the pressure difference between the indoor and outdoor environment. At one point of the building envelope under positive pressure, air leaks into the internal environment, while at another point under negative pressure, air leaks into the external environment. Thus, the airtightness mechanism works in a cycle (ASHRAE, 2013; Lawson, 1980).

Airtightness mechanism can be analysed under three main headings as wind effect, chimney effect and mechanical air conditioning devices. Wind effect is the phenomenon of positive pressure on the facades of the building shell facing the prevailing wind and negative pressure on the facades sheltered from the wind when the wind hits the outer surface of the building. The vertical air movement inside the building due to the pressure difference between the indoor and outdoor temperature difference is called the chimney effect. It can be said that the chimney effect is related to the indoor air density and building height (Lawson, 1980; IECC, 2012; Straube, 2012).

Mechanical air conditioning systems are used to provide indoor air quality in places that cannot be ventilated sufficiently with natural ventilation. In ventilation with mechanical air conditioning systems, pressure difference occurs as a result of air movements inside the building (URL – 1; IECC, 2012). As seen in Figure 3, when mechanical air conditioning devices are used, the indoor pressure is lower than the outdoor pressure and air leaks may occur through cracks in the building envelope.

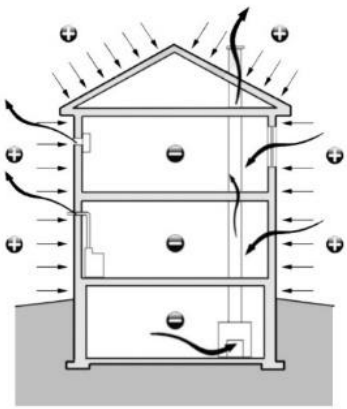

Figure 3. Airtightness in the building envelope with the effect of mechanical air conditioning system (Sular, 2006).

Studies on Building Envelope Airtightness Performance Over Time;

To the present day, many studies have been carried out in different countries to investigate the air tightness performance of the existing building stock. In the study conducted in Greece, BDT was measured in 20 houses. As a result of the study, it was reported that the analysed buildings showed low air tightness performance (Sfakianaki, 2008). There are studies supporting that the construction time of the buildings also affects the air tightness performance. In 2012, as a result of the study in which the air tightness performances of the houses were investigated by measuring the BDT in 20 houses in Italy, it was stated that the air tightness n50 values of

the houses built before 1970 were high and therefore showed low building envelope tightness performance (Alfano, 2012). In another study conducted in South Korea, BDT measurements were made in 12 houses and according to the measurement results, it was concluded that the air tightness performance of new buildings was 3 – 4 times higher than the old buildings (Hong, 2022). However, in the study conducted in Denmark, contrary to these results, it was found that the air tightness performance of old buildings was better than expected (Mortensen, 2017). In this case, it is thought that the construction techniques and workmanship of the houses built in the past in that region are better.

Walls with thermal insulation are effective in maintaining the indoor temperature as well as on building envelope tightness. As a result of the study in which the air tightness performances of 226 houses in Finland were measured by BDT measurement, it was concluded that the houses with thermal insulation applied to the wall surfaces showed higher building envelope tightness performance (Vinha, 2015). Like the materials used in the building envelope, the quality of the on-site application of these materials is also very effective on the building envelope sealing performance. As a result of the study in which 44 houses built by different master teams of the same construction company in Norway were considered as a field study, it supports that the quality of workmanship has an effect on air tightness (Colijn, 2017). Whether the building consists of detached or multiple dwellings is also a parameter that affects the building envelope tightness performance. According to the results of a study of 129 houses in Spain, the average air permeability ratio (q50) of detached houses was found to be higher than apartments (Feijó-Muñoz, 2019). Another study addressing defects in construction quality evaluates the effect of lightweight timber cladding system on hygrothermal performance and air tightness. It was concluded that holes in the air barrier, staples in the vapour barrier, nails directed to the external insulation and separated structural elements negatively affect air tightness in structures with timber cladding and that holes in the air barrier significantly increase infiltration (Piggot-Navarrete, 2023).

BlowerDoor Test, which is the depressurisation method, and the Pulse Test, which is the impact method, are used to measure the building envelope air tightness performance. In order to test the reliability of these methods, 1 dwelling was taken as a field study in a study conducted in China in 2021. The air tightness performance of the dwelling considered within the scope of the study was measured with both BDT and Pulse Test methods. When the measurement results obtained from Pulse test and CBT fan pressurisation method are compared, it is seen that the results are compatible with each other (Hsu, 2021). In addition to measurement methods, simulation methods are also used to investigate building envelope air tightness performance. In a study conducted in Belgium in 2022, CONTAM air tightness simulation was used and on-site tracer gas measurements were made. According to the results of the study, the heat loss due to infiltration may not be maximum at the design temperature even after multiplying by the temperature difference (Meng, 2022). One of the simulation methods is APMPS, which is an air tightness prediction method. In the study conducted in South Korea in 2023, 3 residential buildings were considered and the measurement results and air tightness prediction results with APMPS were compared. According to the results, the accuracy of APMPS predictions improved as the building height, indoor and outdoor temperature differences increased. In addition, a significant correlation was observed between error rate, height difference and differential pressure at 1% significance level (Park, 2023).

It is known that the materials used in the building envelope are effective on air leaks. In this context, in a study conducted in 2023, wall, ceiling and floor air barrier systems consisting of polyethylene sheets, self-adhesive membranes and concrete structure used in the building envelope were examined. The n50 value, which is the airtightness value of the building per hour, was measured by the BDT measurement method in accordance with ASTM E779 standards. As a result of this study, which deals with a reinforced concrete garage and a single storey wooden building in Britain, it was determined that there was a significant amount of airtightness from the holes in the plasterboard application. It was mentioned that the air tightness performance of the structure was increased with the measures to be taken at the specified points (Vaseghi, 2023).

Airtightness Standards;

Building volume, building envelope area and building floor area are effective in normalising airtightnesss. The combination of very different materials in the building envelope can affect air tightness. Normalisation of airtightness is easier to implement in buildings of adjacent layout. Since the usable area is scaled closest to the building floor area, the normalisation can be better seen. This normalisation can be converted to a different

type of leakage, such as the normalised leakage used by ASHRAE (2001) (Sherman, 2006). Table 1 show the air exchange rates by country and for different types of dwellings.

Table 1. Airtightness conditions in dwellings according to countries (Fennel, 2005).

Standard	Region		Explanation	Requirement	ACH 50 n50
Passive House	**Europe**		<0.6	ACH50	<0.6
	Austria	Naturally ventilated	<3.0	ACH50	<3.0
		Mechanically ventilated	<1.5	ACH50	<1.5
	Bulgaria	Apartment buildings	High tightness	Less than 2	ACH50 less than 2
			Medium tightness	2.0 - 5.0	ACH50 2.0-5.0
			Low tightness	greater than 5.0	ACH50 greater than 5
		Single family houses	High tightness	Less than 4	ACH50 less than 4
			Medium tightness	4.0-10.0	ACH50 4.0-10
			Low tightness	Greater than 10	ACH50 greater than 10
TNI 730330	**Czech Republic**	Natural		4.5	ACH50 4.5
		Forced		1.5	ACH50 1.5
		Forced + heat recovery		1.0	ACH50 1.0
	Denmark	Residential	<1.5	(L/s50)/m^2	<6.1
	France	Single family houses	<0.8	(m^3/h4)/m^2	<4.5
	Germany	With ventilation system	<1.5	ACH50	<1.5
		No ventilation system	<3	ACH50	<3.0
	Netherlands	With ventilation system	<2-3	ACH50	2-3
		No ventilation system	<4-6	ACH50	4-6
	Portugal	Residential	<0.6	ACH50	<0.6
TS 825	**Turkey**	Multi-storey building	High	ACH 50 less than 2	ACH50 < 2
			Medium	2-5 ACH 50	ACH50 2-5
			Low	ACH50 greater than 5	ACH50 greater than 5
		Single storey building	High	ACH50 less than 4	ACH50 less than 4
			Medium	ACH50 4.0-10.0	ACH50 4.0-10.0
			Low	ACH50 greater than 10	ACH50 greater than 10

4.Conclusion and Recommendations

In this study, building envelope airtightness, which is directly related to energy consumption in buildings, is discussed. Within the scope of the study, researches on "building envelope tightness", "energy efficiency", "thermal comfort" were conducted through databases. Within the framework of the researches carried out, it has been stated in the studies that building envelope air leaks, especially during heating periods, adversely affect the thermal comfort by passing the heated air in the interior through the cracks in the building envelope and in addition to this, the heating load will increase.

The principle of "airtight construction", which is one of the passive house design criteria, plays an important role in sustainable building design projects in many countries. In many countries, which is limited by standards.

"Passive House Standard" in Germany and Bulgaria and "TNI730330 Standard" in the Czech Republic contain important rules on building envelope tightness. In Turkey, there are only limit values in the "TS 825 Standard for Thermal Insulation Rules in Buildings" regarding building envelope tightness. It is necessary to draw attention to the importance of building envelope sealing, which has a significant impact on energy consumption in Turkey. The air tightness performance of the existing building stock should be investigated in academic studies. In addition, laws and standards on air tightness in buildings should be introduced and attention should be drawn as a parameter to be considered in building construction.

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DECARBONIZATION OF TRANSPORTATION AND BUILDING SECTORS IN TURKEY

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ABSTRACT

In Turkey, the building and transportation sectors account for 56% of total final energy consumption. These sectors consume an extensive amount of fossil fuels. Natural gas accounts for 45% of the final energy consumption in the building sector, whereas petroleum products account for 98% of the final energy consumption in the transportation sector. By the year 2053, Turkey is committed to achieving net zero emissions. This ambitious goal entails a strategic focus on curtailing energy consumption and minimizing the reliance on fossil fuels within the transportation and building sectors, thereby mitigating greenhouse gas emissions. Transition of of the energy system and increased electrification with renewable energy sources (RESs) will reduce external dependence on energy and Turkey's current account deficit. In this study, energy consumption in the transportation and building sectors in Turkey is analyzed and solutions for decarbonization of these sectors are presented. This review provides a perspective on the current status of the main technologies that can be used to decarbonize the transportation and building sectors and the opportunities that these technologies will offer in the future. This perspective is expected to contribute to the researchers who will carry out scientific studies in the related sectors in determining the study topics. In order to reduce transportation and sector emissions in Turkey, the electrification of these sectors should be increased and the electricity needed should be supplied from RESs. The number of electric vehicles (EVs) in road transportation, whose share in final energy consumption of the transport sector is approximately 94%, should be increased. RESs ought to be used for the generation of electricity required to power EV charging stations. A significant portion of the energy consumed in buildings in Turkey is provided by fossil resources, and about 46% of building energy consumption is met by natural gas. In order to reduce building sector emissions in Turkey, the use of RESs in buildings should be increased. To facilitate the electrification of buildings, it is advisable to employ heat pumps, given their increasing cost competitiveness and the escalating global trend towards their widespread adoption. The energy performance of buildings with poor energy efficiency should be enhanced, and new constructions should be ensured to be at least nearly zero-energy buildings. The increase in electrification facilitated by the use of RESs will contribute to the attainment of Sustainable Development Goals.

Keywords: Transportation, buildings, heat pumps, nearly zero energy buildings, electric vehicles, renewable energy sources, sustainable development goals.

TÜRKİYE'DE ULAŞTIRMA VE BİNA SEKTÖRLERİNİN KARBONSUZLAŞMASI

ÖZET

Türkiye'de ulaştırma ve bina sektörlerinin nihai enerji tüketimindeki toplam payı %56'dır. Bu sektörlerde fosil yakıt kullanım oranı yüksektir. Ulaştırma sektöründeki nihai enerji tüketiminin %98'i petrol ürünleriyle, bina sektöründeki nihai enerji tüketiminin %45'i doğalgaz ile karşılanmaktadır. 2053 yılında net sıfır emisyon hedefleyen Türkiye'de, ulaştırma ve bina sektörlerindeki enerji tüketimlerinin ve fosil yakıt kullanımlarının azaltılması, sera gazı emisyonlarını azaltacaktır. Elektrik üretim sisteminin yenilenebilir enerji odaklı dönüşümü, enerji verimliliği ve elektrifikasyonda yaşanacak artış Türkiye'nin enerjide dışa bağımlılığını ve cari açığını azaltacaktır. Bu çalışmada, Türkiye'de ulaştırma ve bina sektörlerin karbonsuzlaşması için uygulama ve politika önerileri sunulmuştur. Bu derleme çalışmasında, ulaştırma ve bina sektörlerini karbonsuzlaşmasında kullanılabilecek başlıca teknolojilerinin mevcut durumu ve bu teknolojilerin gelecekte sunacağı fırsatlar ile ilgili bir perspektif ortaya konulmuştur. Bu perspektifin, ilgili sektörlerde bilimsel çalışma gerçekleştirecek araştırmacılara, çalışma konularının belirlenmesinde katkı sunması beklenmektedir.

Türkiye'de ulaştırma ve sektörü emisyonlarının azaltılması için, bu sektörlerin elektrifikasyonu artırılmalı ve ihtiyaç duyulacak elektrik enerjisi yenilenebilir enerji kaynakları (YEK)'lerden sağlanmalıdır. Ulaştırma sektörü nihai enerji tüketimi içindeki payı yaklaşık % 94 olan karayolu ulaşımındaki elektrikli araç (EA) sayısı artırılmalıdır. EA şarj istasyonlarının ihtiyaç duyduğu elektrik enerjisi YEK'ler kullanılarak üretilmelidir. Türkiye'de binalarda tüketilen enerjinin önemli bölümü fosil kaynaklar kullanılarak sağlanmakta olup, bina enerji tüketiminin yaklaşık %46'sı doğalgaz ile karşılanmaktadır. Türkiye'de bina sektörü emisyonlarının azaltılması amacıyla, binalarda YEK kullanımı artırılmalıdır. Binaların elektrifikasyonunun sağlanması için, maliyet açısından daha rekabetçi hale gelen ve Dünya genelindeki kullanımı hızlı biçimde artan ısı pompaları kullanılmalıdır. Zayıf enerji performansına sahip binaların enerji performansları iyileştirilmeli, yeni binaların en azından neredeyse sıfır enerjili bina olarak yapılması sağlanmalıdır. YEK kullanılarak sağlanacak olan elektrifikasyon artışı, Sürdürülebilir Kalkınma Hedeflerine erişilmesini destekleyecektir.

Anahtar kelimeler: Ulaştırma, Binalar, fosil yakıt, sera gazı emisyonu, neredeyse sıfır enerjili binalar, elektrikli araçlar, yenilenebilir enerji kaynakları, sürdürülebilir kalkınma hedefleri.

1. Giriş

Küresel ortalama sıcaklık artışı sanayi öncesi seviyelerin yaklaşık 1,2 C° üzerindedir. Enerji dönüşümünün güvenli bir şekilde gerçekleşmesi, küresel ortalama sıcaklık artışının sanayi öncesi döneme göre 2 C°, mümkünse 1,5 C° altında tutulabilmesine bağlıdır **[1]**. 2022 yılındaki küresel enerji krizi sonrası Dünya, yenilenebilir enerjiye dayalı bir enerji sistemine geçmekte, elektrik kullanımı artmaktadır. Elektrik kullanımındaki artışın en önemli nedeni, ulaştırma ve ısınma amaçlı kullanımlardaki elektrik enerjisi tüketimi artışıdır **[1]**. Uluslararası Yenilenebilir Enerji Ajansı (IRENA)'nın 1,5 C° senaryosuna göre, sıcaklık artışının 1,5 C° ile sınırlandırılabilmesi için, 2020 yılında %22 olan nihai enerji tüketimindeki doğrudan elektrik kullanım oranını, 2050 yılında %51 'e çıkarılması gerekmektedir. Nihai enerji tüketimindeki doğrudan elektrik kullanım oranının 2050 yılında %51 düzeyinde olması durumunda, elektriğin %91'i Yenilenebilir enerji kaynakları (YEK)'lerden sağlanacaktır **[2].**

YEK'ler enerji dönüşümünün temel kaynağı durumundadır. Dünya genelinde fosil olmayan kaynakların enerji karmasındaki payı %20 olup, bu oranın 2050 yılında %52'ye yükselmesi beklenmektedir. 2025 yılından itibaren, yeni eklenen kapasitenin neredeyse tamamı fosil olmayan kaynaklardan oluşacaktır. 2022-2050 yılları arasında rüzgar kapasitesi on kat, güneş kapasitesi on yedi kat artacaktır. YEK'lerin 2022 yılında elektrik enerjisi üretimindeki oranı %31 olup, bu oran 2050 yılında %82'ye yükselecektir. 2050 yılında YEK ile üretilen üretilen elektriğin yaklaşık %50'si güneş enerjisi ile sağlanacaktır **[3]**.

YEK'ler, iklim değişikliğini önler, enerji maliyetlerini azaltır, sürdürülebilirlik ve enerji arz güvenliği sağlarlar. YEK'lerin gelişmesi, ekonomik büyüme ve istihdam artışı sağlar, insan sağlığı ve refahını artırır **[4, 5, 6].** Dünya genelinde yenilenebilir enerji kurulu gücü artışı sürmektedir. 2022 yılında yaklaşık 340 GW'lık yenilenebilir enerji kapasitesi devreye alınmış, bu alanda 600 milyar dolarlık yatırım gerçekleştirilmiştir. Yenilenebilir enerji kurulu gücünde yaşanan büyüme büyük oranda fotovoltaik (FV) güneş enerjisi kaynaklı olmuştur **[7].** Güneş enerjisinin yaygınlaştırılması için günde 1 milyar ABD dolarından fazla yatırım yapılmaktadır. FV güneş modüllerinin temel bileşenlerine yönelik üretim kapasitesi hızla artmaktadır **[1]**.

YEK'ler ile sürdürülebilir kalkınma hedefleri (SKH) arasında güçlü bir sinerji vardır. YEK'lerden yararlanılması durumunda SKH'larda belirlenen birçok hedefe erişilmiş olacaktır **[4].** YEK teknolojilerinin kullanılması SKH 7 hedefine erişimi sağlar. Herkes için satın alınabilir, güvenilir, sürdürülebilir ve çağdaş enerjiye erişimi sağlamayı hedefleyen 7. SKH'a erişilmesi kapsamındaki hedefler; yoksulluğu önler, gıda güvenliğini sağlar, sağlık ve kaliteli yaşam sağlar, insana yakışır iş ve ekonomik büyüme sağlar, eşitsizlikleri azaltır. Özellikle, şebekeden bağımsız FV güneş enerjisi santralleri (GES), küçük topluluklara enerji arzının daha katılımcı biçimde yönetilmesine olanak tanırlar **[5].**

Dünya genelinde, 2022 yılı için 29,5 PWh olan elektrik tüketimi, 2050 yılında 60,8 PWh değerine ulaşacaktır. 2050 yılında elektrik sektörünün toplam enerji sektörü içindeki payı %35 olacaktır **[3].** İnsan faaliyeti kaynaklı sera gazı emisyonlarının %64'ü fosil yakıtların yakılması (elektrik üretimi, ısı, güç ve endüstriye işlemler için) sonucu meydana gelen CO_2 emisyonlarından oluşmaktadır **[8].** 2022 yılı elektrik üretim sektörü emisyonları toplam enerji kaynaklı CO_2 emisyonları içindeki payı %40(13,4 Gt) olmuştur **[3]**. FV GES, rüzgar enerjisi ve elektrikli araç (EA)'ların, küresel enerji sektörü CO_2 emisyonlarının azalmasına yaptığı katkı artarak sürecektir. Kurulumu artan FV GES'ler ve rüzgar enerjisi santralleri (RES) ile artan EA sayısı

nedeniyle, 2030 yılındaki küresel enerji sektörü CO_2 emisyonları yaklaşık 6 Gt azalacaktır. Bu azalmaya, FV GES'lerin yaklaşık 3 Gt, RES'lerin yaklaşık 2 Gt ve EA'ların ise yaklaşık 1 Gt katkı sağlayacağı öngörülmektedir **[1]**.

Avrupa Birliği (AB)'de, 2021 yılında tüketilen enerji içindeki yenilenebilir enerji payı %22'dir **[9].** AB emisyonlarının %75'i enerji kullanımı kaynaklıdır. AB'nin 2050 yılına kadar ilk iklim nötr kıta olma hedefleri ile uyumlu hale getirilmesi için, YEK'lerden daha fazla faydalanılması ve daha fazla enerji tasarrufu yapılması amaçlanmaktadır **[10].** AB, enerji arz güvenliğini sağlamak ve iklim değişikliğini önlemek amacıyla belirlediği hedeflere ulaşmak amacıyla, YEK'lerden daha fazla yararlanmak ve enerji verimliliğini artırmak amacıyla bir dizi yasal düzenleme gerçekleştirmiştir. AB Yenilenebilir Enerji Direktifi (2009/28/EC) 2009 yılında yayımlanmıştır. AB'nin hızlı bir biçimde temiz enerji dönüşümünü sağlamak amacıyla direktif 2018' de güncellenmiş (Directive (EU) 2018/2001) Haziran 2021 den itibaren de hukuki anlamda bağlayıcı kılınmıştır. Bu bağlayıcı hükme göre, AB'nin 2030 yılına kadar enerji karması içindeki YEK hedefi %32'dir **[11]**. AB Konseyinin 9 Ekim 2023 tarihinde aldığı karar ile, 2030'a kadar AB'nin toplam enerji tüketiminde YEK'lerin payının en az % 42,5'a, mümkünse % 45'e yükseltilmesi hedeflenmiştir. AB üye ülkeleri bu ortak hedef kapsamında gerekli düzenlemelerini gerçekleştireceklerdir. 2030 YEK hedefine daha hızlı ulaşılabilmesi amacıyla, sektörel bazda hedefler belirlenmiş, böylelikle YEK'lerden daha fazla yararlanma amacı güdülmüştür **[12].** AB' nin hukiki açıdan bağlayıcı emisyon hedefi, 2030 yılındaki net sera gazı emisyonlarının 1990'a kıyasla en az %55 azaltılmasıdır **[13].** Eylül 2023 de AB'nin yeni Enerji Verimliliği Direktifi yayımlanmıştır. Güncellenen Enerji Verimliliği Direktifinde; AB'nin nihai enerji tüketimininin AB 2020 referans senaryosuna göre 2030 yılına kadar %11,7 oranında azaltması hedeflenmiştir. Bu hedefe ulaşılması durumunda, AB'nin 2030 yılındaki nihai enerji tüketimi 763 milyon ton eşdeğer petrol (Mtep), birincil enerji tüketimi ise 992,5 Mtep den fazla olmayacaktır **[14].** AB Yeşil Mutabakatı, Fit for 55 ve RePowerEU politikaları, Avrupa'yı 2050 yılına kadar sera gazı emisyonlarının net olarak sıfırlandığı dünyanın ilk iklim-nötr kıtası haline getirme hedefini daha gerçekçi kılmakta, AB'nin karbonsuzlaşma politikalarının sonuç verebileceğini göstermektedir **[3].**

Türkiye'de birincil enerji kaynakları içerisindeki fosil yakıtların payı yüksek olup, Türkiye bu kaynakların arzında yüksek oranda dışa bağımlıdır. Türkiye'nin 2021 yılında toplam birincil enerji arzı 159,4 Mtep olarak gerçekleşmiş olup, toplam birincil enerji arzı içindeki fosil kaynak oranı %84,5'dir(134,781 Mtep). Doğalgazın toplam birincil enerji arzı içindeki payı %31(49,23 Mtep), ham petrolün toplam birincil enerji arzı içindeki payı %23 (36,24 Mtep), taş kömürünün toplam birincil enerji arzı içindeki payı ise %15'dir (23,44 Mtep). Birincil enerji arzındaki en yüksek paya sahip ilk üç kaynak olan doğalgaz, ham petrol ve taş kömürünün ithalat oranları sırasıyla; %98, %91 ve % 98'dir. Türkiye'nin birincil enerji kaynaklarında dışa bağımlılık oranı %78'dir. Türkiye'nin 2021 yılı toplam nihai enerji tüketimi değeri 123,859 Mtep'dir. Doğalgazın toplam nihai enerji tüketimi içindeki payı %24 (29,70 Mtep), petrol ürünlerinin toplam nihai enerji tüketimi içindeki payı % 35,7 (44,23 Mtep) ve taş kömürünün toplam nihai enerji tüketimi içindeki payı ise % 5,56'dır (6,90 Mtep) **[15].**

Türkiye'nin fosil yakıtların arzında yüksek oranda dışa bağımlı olması, Türkiye'nin ekonomi göstergeleri açısından önemli bir sorun oluşturmaktadır. Türkiye'nin enerji ithalat bedeli, toplam ithalat bedeli içerisinde önemli bir paya sahip olmaya devam etmektedir. 2013 yılında enerji ithalat bedelinin toplam ithalat içindeki oranı %22,5'dir. Türkiye'nin 2022 yılı toplam ithalat bedeli 363,71 milyar dolardır. 2022 yılı enerji ithalat bedeli 96,5 milyar dolar olup, toplam ithalatın % 26,5' i enerji ithalatı kaynaklıdır **[16].** 2013 yılında 57,75 milyar dolar olan enerji ithalat bedeli, 2022 yılında 96,5 milyar dolara yükselmiştir **[16].**

Türkiye'nin sera gazı emisyonları artışını sürdürmektedir. Türkiye'nin 2021 yılı sonu itibariyle toplam sera gazı emisyon değeri 564,4 $MtCO_2$ eşdeğeri (eşd.) olmuştur **[17].** Türkiye'nin seragazı emisyonu, hiçbir önlem alınmaması durumda 2030 yılında 1,175 $MtCO_2$ eşd. değerine ulaşacaktır. Türkiye Cumhuriyeti'nin Birleşmiş Milletler İklim Değişikliği Çerçeve Sözleşmesi Sekreteryası'na sunduğu güncellenmiş Ulusal Katkı Niyet Beyanı'nda, 2030 yılı sera gazı emisyonu "artıştan azaltım" hedefi % 41 olarak belirlenmiştir. Buna göre Türkiye'nin 2030 yılı emisyonları 695 $MtCO_2$eşd. olacaktır. 2053 yılında net sıfır emisyon hedefleyen Türkiye'nin sera gazı emisyonları, 2038 yılında zirve değerine ulaşacaktır **[18].**

Türkiye'nin 2022 sonu tibariyle toplam kurulu güç değeri 103.809,3 MW 'tır. Toplam kurulu güç değerinin %54'ü (56.005,7 MW) yenilenebilir enerji santrallerinden oluşmaktadır. Akarsu tipi HES dışındaki HES ler hariç yenilenebilir enerji santrallerinin toplam kurulu güç içindeki oranı %31'dir (32.730,5 MW) **[19].**

Türkiye'nin rüzgar ve güneş enerjisi potansiyeli yüksektir **[20].** Türkiye'nin 48 GW rüzgar, 50 GW güneş enerjisi kurulu güç kapasitesi vardır **[20].** 2022 yılı sonu itibariyle; rüzgar enerjisi kurulu güç kapasitesinin %24'ü **[19,20]**, güneş enerjisi kurulu güç kapasitesinin %19'u **[19,20]** değerlendirilebilmiştir. 2022 yılı sonu itibariyle, Türkiye'nin 2035 yılı kurulu güç hedeflerine erişme oranları; RES'ler için %38,5 **[19,21],** GES'ler için ise %18'dir [**19,21].** 2035 yılı hedef kurulu güç değerlerine **[21]** erişilmesi halinde ise; Türkiye'nin rüzgar enerjisi kurulu güç potansiyelinin %62'si, güneş enerjisi kurulu güç potansiyelinin tamamı değerlendirilmiş **[20, 21]**olacaktır.

2012 yılında hazırlanan Enerji Verimliliği Strateji Belgesi (2012-2023)'ndeki ana hedef, gayri safii yurt içi hasıla (GSYİH) başına tüketilen enerji miktarının (enerji yoğunluğunun) ve elektrik yoğunluğunu ayrı ayrı olmak üzere 2023 itibariyle 2011 yılına kıyasla %20 azaltmaktır **[22].** Türkiye'nin 2011 yılı birincil enerji yoğunluğu değeri 0,166 tep / 1000 $-2015, 2011 yılı nihai enerji yoğunluğu değeri ise 0,124 tep / 1000 $-2015'dir **[23].** Türkiye'nin 2021 yılı birincil enerji yoğunluğu 0,141 tep/1000 $-2015, nihai enerji yoğunluğu ise 0,110 tep/1000 $-2015 olarak hesaplanmıştır **[24].**

1,5 C° hedefi elektrikle çalışan teknolojilerin kullanımının yaygınlaşması ile başarılabilir. Elektrifikasyon, ekonomik büyümeyi hızlandırmak, enerji güvenliğini artırmak, iklim değişikliğinin artan etkilerini azaltmak ve önemli bazı sürdürülebilirlik hedeflerine ulaşmak için önemli bir araçtır **[2].** Günümüz Dünyasında, merkezinde güneş enerjisi ve EA'ların olduğu yeni bir temiz enerji ekonomisi ortaya çıkmıştır. Isı pompaları, enerji verimliliği iyileştirmeleri ve EA'lar temiz enerji geçişini hızlandırmak için benimsenebilecek başlıca seçeneklerdirler **[1,2]**. Isı pompaları, FV GES ve ve EA teknolojileri belirli bir teknolojik olgunluğa ve fiyatlar açısından rekabet edebilir düzeye ulaşmışlardır **[1]**. 2050 yılında satılan ısıtma ünitelerinin yarısı ısı pompası veya elektrikli ısıtıcı olacaktır. Küresel EA satışları 2022 yılında %50'den fazla artış göstermiş, 10 milyondan fazla EA satılmıştır. 2040 yılında 650 milyon EA'nın yollarda olması beklenmektedir **[1]**.

Türkiye'de ulaştırma ve bina sektörlerinin karbonsuzlaşması, Türkiye'nin belirlediği emisyon hedeflerine erişimi açısından önemlidir. Bu sektörlerde YEK'lerden daha fazla yararlanılması, sektörlerin neden olduğu ekonomik, teknik ve çevresel zararların azaltılmasını sağlayacaktır. Bu çalışmanın amacı, bina ve ulaştırma sektörlerindeki enerji tüketimlerini kaynak bazlı analiz ederek, sektörlerin karbonsuzlaştırılmasında kullanılabilecek çözüm seçeneklerini belirlemektir. Bu bağlamda çözüm seçeneklerinin belirlenmesi için; Dünya, AB ve Türkiye'nin, YEK ve enerji verimliliği konularındaki politika ve hedefleri analiz edilmiştir. Bina sektöründe Isı pompaları ve Neredeyse Sıfır Enerjili Bina (NSEB)'ler, ulaştırma sektöründe ise EA'lar ve yenilenebilir enerji destekli EA şarj istasyonları sektörlerin karbonsuzlaşmasına yönelik başlıca çözüm seçenekleri olarak önerilmiştir.

Çalışma giriş bölümü dışında üç bölümden oluşmaktadır. İkinci bölümde Türkiye'nin ulusal enerji politikasında yer alan hedefler incelenmiştir. Üçüncü bölümde bina sektörü, dördüncü bölümde ulaştırma sektörü incelenmiştir. Çalışmanın son bölümü sonuç ve öneriler bölümüdür. Bu bölümde çalışma sonuçları verilerek, incelenen sektörlerin karbonsuzlaşmasına yönelik çözüm önerileri sunulmuştur.

2. Türkiye'nin Ulusal Enerji Politikasında Yer Alan Hedefler

Türkiye, 2053 net sıfır emisyon hedefini esas alarak; 2035 yılına kadar olan süreç için enerji sektöründeki hedeflerini belirlemiştir. 2035 yılına kadar, Türkiye'nin birincil enerji tüketimi 205,3 Mtep, nihai enerji tüketimi ise 148,5 Mtep değerlerine yükselmektedir. Ulusal enerji planına göre; Türkiye'nin birincil enerji tüketimi içerisindeki YEK'lerin payı, 2035 yılına kadar %23,7'ye yükselmektedir. 2035 yılına kadar, Türkiye'nin elektrik tüketimi 510,5 TWh'e yükselmekte ve elektrik enerjisinin nihai enerji tüketimi içindeki payı %24,9 olmaktadır. 2035 yılına kadar enerji yoğunluğu %35,3 oranında azalmaktadır **[21].**

2035 yılına kadar olan süreçte devreye alınması öngörülen 96,9 GW kapasite ile 2035 yılında elektrik kurulu gücünün 189,7 GW olması planlanmaktadır. GES kurulu gücünün 52,9 GW'a, RES kurulu gücünün 29,6 GW'a (24,6 GW karada, 5 GW denizde), hidroelektrik santral (HES) kurulu gücünün 35,1 GW'a, Jeotermal ve biyokütle enerji santralleri kurulu güç toplamının ise 5,1 GW değerine ulaşması hedeflenmektedir **[21].** 2035 yılı elektrik kurulu gücünde; kesintili YEK'lerin (Rüzgar, Güneş) payı %43,5'e, tüm YEK'lerin payı ise %64,7'ye yükselmektedir. Elektrik üretiminde; kesintili YEK'lerin payı %34,2'ye, tüm YEK'lerin payı ise %54,7'ye yükselmektedir **[21].**

Türkiye'nin 11. ve 12. kalkınma planlarında yer alan enerji sektörü hedefleri ve bu hedeflerin gerçekleşme düzeyleri, enerji sektöründeki gelişme düzeylerinin analizi açısından önemlidir. Türkiye'nin 11. ve 12. kalkınma planlarında hedeflenen ve gerçekleşen değerler Tablo 1'de verilmiştir **[25,26]**.

Tablo 1. Kalkınma Planlarında Yer Alan Enerji Sektörü Hedefleri

	2018 gerçekleşen	2023 hedefi	2022 gerçekleşen	2023 gerçekleşen	2028 hedefi
Birincil Enerji Talebi (BTEP)	147.955	174.279	159.500	165.350	190.000
Elektrik Enerjisi Talebi(TWh)	303,3	375,8	331	325	430
Kişi Başı Birincil Enerji Tüketimi (TEP/Kişi)	1,81	2,01	1,87	1,9	2
Kişi Başı Elektrik Enerjisi Tüketimi (kWh/Kişi)	3.698	4.324	3.883	3.780	4.700
Doğal Gazın Elektrik Üretimindeki Payı (%)	29,85	20,7	22,9	23	15
Yer Altı Doğal Gaz Depolama Kapasitesi (Milyar m3)	5,8	5,8	5,8	5,8	13
Yenilenebilir Kaynakların Elektrik Üretimindeki Payı (%)	32,5	38,8	42,4	40	50
Yerli Kaynaklardan Üretilen Elektrik Enerjisi Miktarı (TWh)	150	219,5	190,4	176	270
Elektrik Kurulu Gücü (MW)	88.551	109.474	103.809	106.800	136.000
Rüzgar Kurulu Gücü (MW)			11.396	11.700	18.000
Güneş Kurulu Gücü (MW)			9.425	11.350	30.000
Enerji Verimliliğinden Sağlanan Tasarruf Miktarı (BTEP)					4.500
Batarya Depolama Kapasitesi (MW)					5.000

Tablo 1'deki veriler incelendiğinde, 11. Kalkınma planında yer almayan enerji verimliliği ve batarya depolama kapasitesi ile ilgili hedeflere, 12. Kalkınma planında yer verildiği görülmektedir. YEK'lerin artan önemi dikkate alınarak, RES ve GES'lerin kurulu güç hedeflerine ayrı başlıklar altında 12. Kalkınma Planında yer verilmiştir. Doğalgazın elektrik üretimi içindeki payını azaltma hedefine erişilememiştir. 11. Kalkınma Planında 2023 yılında doğal gazın elektrik üretimindeki payı'nın %20,7 olması hedeflenmiştir. Ancak 12. Kalkınma planı verilerine göre; 2022 yılı sonu itibariyle doğal gazın elektrik üretimindeki payı %22,9 olarak gerçekleşmiş olup, 2023 yılında %23 olarak gerçekleşeceği tahmin edilmiştir. Doğal gaz'ın elektrik üretimindeki payını azaltma hedefi devam etmektedir. 2028 yılı içi doğal gazın elektrik üretimindeki payının %15 olması hedeflenmektedir **[25,26].**

Kalkınma planlarında YEK'lerin elektrik üretimi içindeki payını artırma hedefine erişilmiştir. 11. Kalkınma Planında 2023 yılında YEK'lerin elektrik üretimindeki payı'nın %38,8 olması hedeflenmiştir. 12. Kalkınma planı verilerine göre; 2022 yılı sonu itibariyle YEK'lerin elektrik üretimindeki payı % 42,4 olarak gerçekleşmiş olup, 2023 yılında %40 olarak gerçekleşeceği tahmin edilmiştir. YEK'lerin elektrik üretimindeki payını artırma hedefi devam etmektedir. 2028 yılı içi YEK'lerin elektrik üretimindeki payının % 50 olması hedeflenmektedir. YEK'lerin kurulu güç içerindeki payını artırma politikası devam etmektedir. 2028 yılı içi RES kurulu gücünün 18.000 MW, GES kurulu gücünün ise 30.000 MW olması hedeflenmektedir **[25,26].**

3. Bina Sektörü

Dünya genelinde 2022 yılında binalarda tüketilen enerjinin değeri 125 EJ olup, bu değer 2050 yılına kadar %30 artarak 161 EJ değerine ulaşacaktır **[3].** Küresel elektrik tüketiminin %90'ından fazlasını bina ve sanayi sektörleri gerçekleştirmektedir **[1].** Binalarda tüketilen elektrik enerjisinin binalarda tüketilen enerji türleri içerisindeki oranı %34'dir **[2,3].** Elektrikli cihaz, ısıtma ve soğutma sistemlerinin sayısındaki artış sonucu meydana gelen elektrifikasyon nedeniyle, başta yükselen piyasa ve gelişmekte olan ekonomiler olmak üzere, binalardaki elektrik enerjisi payı sürekli olarak artmıştır **[1].** Binalarda tüketilen elektrik enerjisinin toplam bina enerji karması içindeki payı 2050 yılında %52 değerine yükselecektir **[3].** IRENA'nın 1,5 C° senaryosuna göre, Paris İklim Anlaşması hedeflerine ulaşmak için bina sektörü elektrik kullanım oranı 2050 yılında %73'e çıkarılmalıdır **[2].**

Binalarda tüketilen elektrik enerjisinin artan payı nedeniyle, gaz tüketimi azalacaktır. 2022 yılında doğal gazın enerji karmasındaki payı %30 iken, bu oran 2050 yılında %24'e düşecektir **[3].** Dünya genelinde doğalgaz tüketiminin büyük bölümü elektrik enerjisi üretimi ve binalar tarafından gerçekleştirilmektedir. Toplam doğalgaz talebinin %39'u güç, %21'i ise bina sektörlerinden olmuştur**[1].** Rusya'nın Ukrayna'yı işgali ve ılıman geçen kışın ardından 2022'de doğal gaz talebi azalmış ve bu düşüş en çok Avrupa'da yaşanmıştır **[1].**

Isıtma (mahal ve su ısıtma), bina enerji talebinin yaklaşık %45'ini ve binalardan kaynaklanan doğrudan CO_2 emisyonlarının %80'ini oluşturmaktadır **[1].** Binalarda ısıtma amacıyla kullanılan enerji nedeniyle, yılda 4 Gt CO_2 emisyonu oluşmaktadır. Bu değer, küresel enerji kaynaklı emisyonların yaklaşık onda biridir **[27].** Isıtma amaçlı enerji üretimi amacıyla çoğunlukla fosil yakıtlar (kömür, petrol ve doğal gaz) kullanılmaktadır **[2].** Küresel doğal gaz talebinin altıda birinden fazlası binalarda ısınma amaçlı gerçekleşmektedir **[27].** Sıcak iklimlerde yaşayan küresel nüfusun yalnızca üçte birinin soğutma cihazlarına sahip olması ve küresel ısınma ile bu sayının artacak olması, gelişmekte olan ülkelerde yaşam standartlarının yükselmesiyle birlikte, soğutma cihazlarına yönelik talebi artıracaktır. Soğutma cihazlarına olan talep artışı sonucu, Soğutma için küresel enerji talebinin 2050 yılına kadar 2016 seviyelerine kıyasla %45 artması ve 12 EJ değerine yükselmesi beklenmektedir. Çoğunlukla binalarda olmak üzere alan soğutması, soğutma için kullanılan enerjinin yaklaşık yarısından sorumludur. Enerjinin geri kalanı ise endüstriyel ve ticari soğutma için kullanılmaktadır. Mevcut durumda, soğutma sistemleri ağırlıklı olarak elektrikle çalıştığından, karbonsuzlaşma kazanımları, akıllı elektrifikasyon stratejileriyle sağlanabilecektir **[2].**

AB'de, nihai enerji tüketiminin %40'ı, enerji kaynaklı emisyonların ise %36'sı binalar kaynaklıdır **[23, 28,29].** Elektriğin %55'i binalarda tüketilmektedir **[28].** Avrupa'da alan ısıtması için tüketilen enerji, bina enerji tüketiminin yaklaşık %70'dir. Avrupa'da konutlardaki ısıtma amaçlı kullanılan enerjinin %37'si fosil yakıtlar kullanılarak sağlanmaktadır **[29].** Avrupa'nın en büyük gaz talebi bina ısıtması kaynaklıdır. AB'de doğalgaz talebinin üçte biri binalarda ısınma amaçlı gerçekleşmektedir **[27].** 2030 yılında Avrupa'nın bina ısıtması kaynaklı doğalgaz talebinin en az 21 milyar m^3 olacağı tahmin edilmetedir **[27].** Bu bakımdan binalar, AB'nin 2030 yılı enerji ve iklim hedeflerine ulaşmasında anahtar role sahiptirler **[28].**

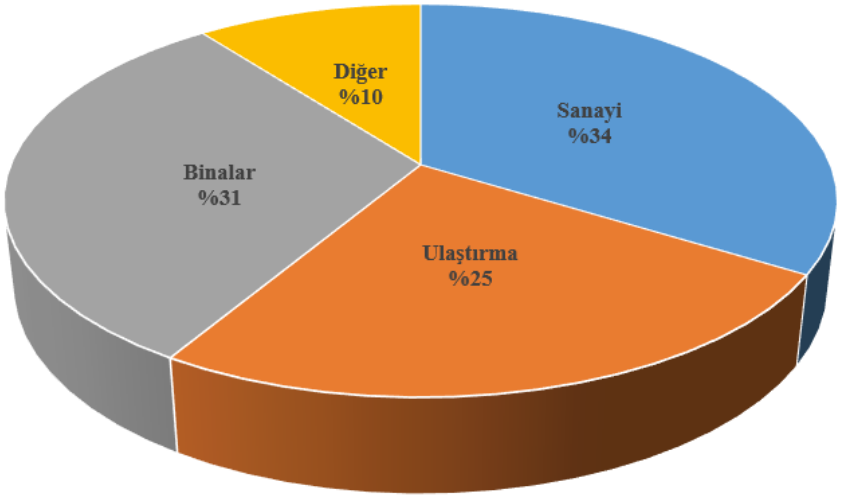
AB'de Isıtma ve soğutma sistemlerinde YEK'lerden daha fazla yararlanılması hedeflenmiştir. Bu bağlamda ısıtma ve soğutmada YEK kullanımını artırmak için yıl bazlı olarak belirlenen ve yıllar ilerledikçe artan YEK kullanım oranları belirlenmiştir **[14].** AB'de 2030 yılına kadar binalarda kullanılan enerjinin en az %49'unun YEK'lerden sağlanması hedeflenmektedir **[12].** AB'nin bina stoğunun %75'i zayıf enerji performansına sahiptir. Üye ülkeler enerji performanslarını güncellemeli, en azında NZEB veya sıfır enerjili bina olmalıdırlar **[14].**

Türkiye'nin 2021 yılı toplam nihai enerji tüketimi 123,859 Mtep'tir. Türkiye'nin sektörlere göre nihai enerji tüketimleri Tablo 2'de verilmiştir **[15]**.

Tablo 2. Sektörlere göre nihai enerji tüketimleri

Sektör	Nihai Enerji Tüketimi (Mtep)
Sanayi	41,614
Ulaştırma	30,562
Binalar	38,121
Diğer	12,846
Toplam	123,859

Bina sektörünün enerji tüketim miktarı 38,121 Mtep'dir **[15]**. Türkiye'nin sektör bazlı tüketimin toplam nihai enerji tüketimi içindeki oranları Şekil 1'de verilmiştir **[15].**



Şekil 1. Toplam nihai enerji tüketiminin sektörlere göre dağılımı

Bina sektörünün Türkiye'nin toplam nihai enerji tüketimi içindeki oranı %31'dir **[15].** Bina sektörünün nihai enerji tüketimi için gerekli enerji çeşitli kaynaklar kullanılarak sağlanmaktadır. Bina sektörü nihai enerji tüketiminin kaynaklara göre dağılımı Tablo 3'de verilmiştir **[15].**

Tablo 3. Bina sektörü nihai enerji tüketiminin kaynaklara göre dağılımı

Kaynak	Nihai Enerji Tüketimi (Mtep)	Oran (%)
Taş kömürü	2,035	5,34
Linyit	2,374	6,23
Asfaltit	0,121	0,32
Petrol ürünleri	0,895	2,35
Doğalgaz	17,698	46,43
Biyoenerji ve Atıklar	1,528	4,01
Elektrik	11,521	30,22
Jeotermal	1,328	3,48
Güneş	0,559	1,47
Diğer	0,630	1,65
Toplam	38,121	100,00

Tablo 3'deki verilere göre; bina enerji tüketiminin yaklaşık %46'sı doğalgaz, yaklaşık %30'u ise elektrik enerjisi ile karşılanmaktadır **[15].**

Türkiye'de, alan ısıtma ve soğutma, sıcak su, pişirme, mesken enerji tüketiminin yaklaşık %80-85'ini oluşturmakta olup, alan ısıtma tek başına mesken enerji tüketiminin yaklaşık %50-60'ını oluşturmaktadır **[21].** Türkiye Ulusal enerji planında, emisyon azaltımının sağlanabilmesi için belirli tarihten itibaren binalarda ısıtma amaçlı fosil yakıt kullanımının sonlandırılacağı belirtilmiştir **[21].**

Bina sektörü, küresel ölçekte sera gazı emisyonlarının azaltılmasında önemli bir role sahiptir. Bina sektöründe, fosil yakıtlar yerine elektrik kullanan bir çok teknoloji kullanılabilmektedir. FV GES'ler ve ısı pompaları yeni yapılacak ve yenilecek binalar için sera gazı emisyon azaltımı için kullanılabilecek başlıca çözümler arasında yer almaktadırlar**[30].** Binaların yeni teknolojilerle sürdürülebilirlik odaklı dönüşümü, yeni iş fırsatı yaratma

potansiyeline sahiptir **[30].** NSEB'ler bina sektörünün karbonsuzlaşmasında kullanılacak diğer başlıca seçeneklerdendir. Yüksek enerji performansına sahip olan NSEB'lerin ihtiyaç duyduğu neredeyse sıfır veya çok düşük enerji talebi, yerinde veya yakınında bulunan bir yenilenebilir enerji tesisinden karşılanmaktadır.

3.1. Isı Pompaları

Küresel ısınmanın dünya gündeminde ön sıralarda yer alması ve artan fosil yakıt maliyetleri ısı pompalarına olan ilgiyi artırmıştır. Verimli bir şekilde ısıtma ve soğutma sağlayabilen ısı pompaları, sera gazı emisyonlarını azaltmada uygulanabilir çözümler arasında yer alırlar. Isı pompaları, alan ısıtması ve ısı üretiminde CO_2 emisyonlarını büyük ölçüde azaltma potansiyeline sahip teknolojilerdir **[31].** 2021 yılında küresel olarak alan ısıtma ihtiyaçlarının yaklaşık %10'u ısı pompaları tarafından karşılanmıştır. Isı pompalarının kurulumu hızlı bir şekilde artmaktadır **[27].** Özellikle gelişmiş ekonomilerde görülen ısı pompa satışlarındaki artış, gaz yakıtlı kazan satışlarında görülen azalma trendinin temel nedenidir **[1].** Isı pompaları, küresel CO_2 emisyonlarını 2030 yılında en az 500 milyon ton azaltma potansiyeline sahiptir **[27].** Isı pompalarının emisyon azaltım etkisi, ısı pompasının türüne ve pompanın elektrik ihtiyacını karşılamada kullanılan enerjinin türüne bağlı olarak değişmektedir **[31].** Yenilenebilir enerji ile çalışan ısı pompaları, küresel iklim değişikliğinin güvenli ve sürdürülebilir ısıtmaya geçişinde önemli bir çözüm aracıdır **[27].**Yenilenebilir enerji ile çalışan ısı pompaları, fosil yakıtla çalışan ısı pompalarına göre daha fazla emisyon azaltımı gerçekleştirebilirler **[27, 32].**

Günümüz dünyasında, binaların çoğunluğu doğalgaz ile ısıtılmaktadır. Doğalgaz ile yapılan ısıtma, sera gazı emisyonuna yol açmaktdır. Ukrayna – Rusya arasındaki savaş kaynaklı küresel enerji krizi, bina ısıtması için daha uygun fiyatlı, güvenilir ve sürdürülebilir enerji kaynakları kullanımı gereksinimini daha kaçınılmaz hale getirmiştir. Bu bağlamda, binalara ve endüstriye verimli bir şekilde ısıtma sağlayabilen ısı pompaları, ısıtmayı daha güvenli ve sürdürülebilir hale getirmek için anahtar teknolojidir. Isı pompaları, hızlı bir şekilde maliyet açısından daha rekabetçi hale gelmekte ve dünya genelindeki kullanımı artmaktadır. Isı pompaları, Avrupa için Rus gazına olan bağımlılığı azaltacak önemli bir çözümdür. Isı pompası soğutma amaçlı da kullanılabillir ve ayrı bir klimaya olan ihtiyacı ortadan kaldırır. Isı pompaları, 2050 yılına kadar ısıtma ve soğutma gerektiren alanlarda yaşayacak olan 2,6 milyar insan için ayrı bir klima ihtiyacını ortadan kaldıracaktır **[27].** 2050 yılında ısı pompası ortam ısıtması için gerekli enerjinin %32'sini, sıcak su için gerekli enerjinin %22'sini sağlayacaktır **[3].**

IRENA'nın 1,5 C° senaryosuna göre, Paris İklim Anlaşması hedeflerine ulaşmak için 2020 de 58 milyon olan binalarda kullanılan Isı Pompası sayısı 2050 yılında 793 milyona çıkarılmalıdır **[2].** Türkiye 2053 yılı net sıfır emisyon hedefine ulaşmak amacıyla, YEK kaynaklı elektrik üretimi kullanım oranını artırmayı hedeflemektedir. Türkiye'nin enerji politika ve hedeflerinin yer aldığı 12. kalkınma planında, ısı pompalarının yaygınlaştırılması gerekliliğine yer verilmiştir **[26].**

3.2. Neredeyse Sıfır Enerjili Binalar

NSEB'ler enerji verimliliği ile YEK'lerin birlikte kullanımını esas alan stratejinin önemli bir unsurdurlar **[28].** Çevreye verdiği olumsuz etkileri az olan, doğal kaynak kullanımı azaltan ve vatandaşlar için sağlıklı yaşam alanları üreten binalar SKH ulaşmayı desteklerler. SKH'ler, sürdürülebilir toplum, iklim değişikliği ile mücadele ve barış içinde yaşayan topluluklar yaratmayı amaçlar. Bu bağlamda binalar önemli bir role sahiptirler. SKH 3,7,11 sürdürülebilir bir bakış açısıyla şehirleri ve insan yerleşimlerini kapsayıcı, güvenli ve dayanıklı hale getirmeyi amaçlamaktadır **[33].** NSEB'ler enerji verimliliği sağlayan ve yenilenebilir enerji kullanan binalardır. Bu özellikleri nedeniyle, karbon emisyonlarını azaltarak, SKH'lere katkıda bulunmaktadırlar. Erişilebilir ve temiz enerji (SKH 7), İnsana yakışır iş ve ekonomik büyüme (SKH 8), Sağlık ve kaliteli yaşam (SKH 3), Amaçlar için ortaklıklar (SKH 17), Sürdürülebilir Şehirler ve topluluklar (SKH 11), ve Sanayi yenilikçilik ve alt yapı (SKH 9) SKH'lerini desteklerler.

Türkiye'nin 2024-2026 dönemine ilişkin; hedef ve politikalarının yer aldığı Orta Vadeli Program (OVP)'de, enerji dönüşümü amacıyla uygulanacak politikalarda belirlenmiştir. OVP'de; "Yeşil Dönüşüm" başlığı altında, 2053 net sıfır emisyon hedefini gözeten bir yaklaşımla yeşil dönüşüm sürecinin hızlandırılması tesbiti yapılarak, enerji verimliliği alanında hedefler belirlenmiştir. Bu hedeflerden biride, kamu, ticari ve konut amaçlı binalarda NSEB yaklaşımını yaygınlaştırılacak düzenlemelerin yapılmasıdır **[34].** 12. kalkınma planında, enerji verimli binaların yaygınlaşıtırılması gereğine yer verilmiştir. Bu kapsamda, NSEB tanımının

iyileştirilmesi ve geliştirilmesi ve bu binalar ile ilgili farkındalık artırıcı faaliyetlerin yaygınlaştırılması hedefi belirlenmiştir **[26].**

4. Ulaştırma sektörü

Dünya enerji tüketimi içerisindeki ulaştırma sektörünün payı %25 olup**[8],** ulaştırma sektörü emisyonları toplam enerji kaynaklı CO_2 emisyonların %25'ini (8,5 $GtCO_2$) oluşturmaktadır **[3, 35].** 2022 yılında 121 EJ olan ulaştırma sektörü enerji tüketim miktarı, 2050 yılına gelindiğinde %9 azalarak 111 EJ değerine düşecektir **[3].** Karayolu taşımacılığı küresel petrol talebinin yaklaşık %45'ini oluşturmaktadır**[1]**. 2022-2050 yılları arasında EA sayısında yaşanan artış, elektrifikasyon ve artan verimlilik nedeniyle; ulaşım sektöründe tüketilen petrol miktarı %46, ulaştırma sektörü kaynaklı emisyonların değeri ise %44 oranında azalacaktır **[3].** Bu on yılın sonunda, karayolu taşımacılığı artık bir petrol talebi kaynağı olmaktan çıkacaktır **[1].**

IRENA'nın 1,5 C° senaryosuna göre, Paris İklim Anlaşması hedeflerine ulaşmak için 2020 yılında %1 olan ulaştırma sektörü elektrik kullanımı oranı, 2050 yılında %52'ye çıkarılmalıdır. Bu hedefe ulaşmak için; 2022 yılında 10,5 milyon olan EA sayısı 2050 yılında 2,1 milyar'a 2020 yılında 1 milyon olan EA şarj cihazı sayısı 2050 yılında 2 milyar 300 bin'e çıkarılmalıdır **[2].** İçten yanmalı motor (İYM)'lerin yerini EA'lar almaktadır. 2020 yılında dünya genelindeki otomobilerin %4'ü EA'lardan meydana gelmiştir. Bu oranın 2023 yılında %18'e ulaşacağı tahmin edilmektedir. EA satışlarındaki artış, gelecek yıllarda artarak devam edecektir **[1].** 2022 yılında 2,4 milyar olan kara ulaşımındaki araç sayısı, 2050 yılında 3,5 milyar değerine ulaşacaktır. 2050 yılında dünyadaki araçların %72'si EA olacağı tahmin edilmektedir. Buna karşılık kara yolu taşımacılığındaki EA'ların enerji kullanım oranı %30 olacaktır **[3].** 2050 yılında elektrik sektörünün toplam enerji sektörü içindeki payı %35 olacaktır. Artan elektrik enerjisi payındaki en önemli etken EA sayısındaki artıştır **[3].**

AB'de nihai enerji tüketiminin %30'dan fazlası ulaştırma sektörü tarafından gerçekleştirilmektedir**[14].**

Ulaştırma sektörünün, Türkiye'nin 2021 yılı toplam nihai enerji tüketimi içindeki payı yaklaşık %25'dir (30,562 Mtep). Ulaştırma sektörünün nihai enerji tüketimi için gerekli enerji çeşitli kaynaklar kullanılarak sağlanmaktadır. Ulaştırma sektörü nihai enerji tüketiminin kaynaklara göre dağılımı Tablo 4'de verilmiştir **[15].**

Tablo 4 Ulaştırma Sektörü nihai enerji tüketiminin kaynaklara göre dağılımı

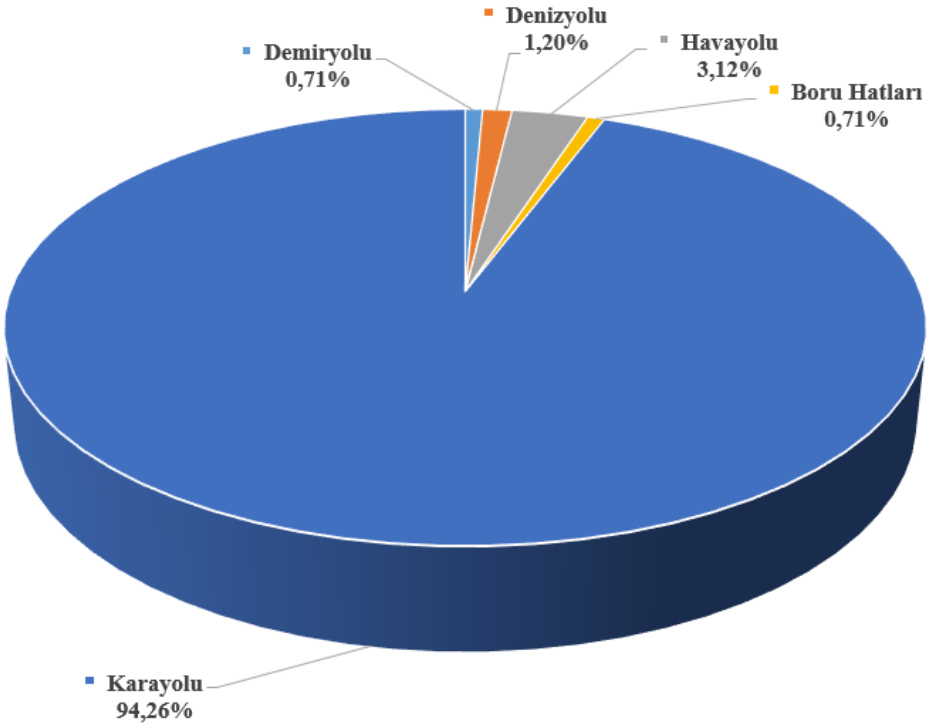
Kaynak	Nihai Enerji Tüketimi (Mtep)	Oran (%)
Petrol ürünleri	29,94	97,96
Biyoenerji ve Atıklar	0,23	0,75
Doğalgaz	0,26	0,85
Elektrik	0,14	0,44
Toplam	30,56	100,00

Ulaştırma sektörü nihai enerji tüketimi içindeki petrol ürünleri payı yaklaşık % 98'dir (29,94 Mtep). Ulaşım türlerine göre nihai enerji tüketimleri Tablo 5'de verilmiştir**[15].**

Tablo 5 Ulaşım türlerine göre nihai enerji tüketimleri

Ulaşım Türü	Nihai Enerji Tüketimi (Mtep)
Demiryolu	0,22
Denizyolu	0,37
Havayolu	0,95
Boru Hatları	0,22
Karayolu	28,81
Toplam	30,56

Ulaştırma sektörü nihai enerji tüketiminin ulaşım türüne göre dağılımı Şekil 2'de verilmiştir**[15].**



Şekil 2. Ulaştırma sektörü nihai enerji tüketiminin ulaşım türüne göre dağılımı

Ulaştırma sektörü nihai enerji tüketimi içindeki karayolu ulaşımı payı yaklaşık % 94'dür **[15].** 2020 yılı verilerine göre, ulaştırma sektörü emisyonlarının değeri 80,7 Mt CO_2 eşd.' olup, bu miktar Türkiye toplam sera gazı emisyonunun yaklaşık %15,5'üdür. Ulaştırma sektörü emisyonlarının %94,9'u karayolu ulaşımı kaynaklı meydana gelmiştir **[18].**

Fosil yakıtlara dayalı bir ulaştırma sektörü, enerji arz güvenliği riski ve finansal yük oluşturur. Ayrıca bu kaynaklar çevre üzerinde olumsuz etkilere sahiptirler. Bu nedenle fosil yakıtlı çalışan araçlardan EA'lara geçilmelidir **[36].**

4.1. Elektrikli Araçlar ve Yenilenebilir Enerji Kullanan Elektrikli Araç Şarj İstasyonları

EA'lar, ulaştırma sektörünün karbonsuzlaştırılmasına ve düşük karbonlı şehirlerin oluşmasına katkı sağlarlar **[37].** EA'lar, fosil yakıtlara ve İYM'li araçlara olan bağımlılığı azaltırlar. EA kullanımı ile çevre kirliliği ve gürültü azaltılabilir **[38]**.

YEK ile elde edilen elektrik enerjisi ile çalışan EA şarj istasyonları, ulaştırma sektörünün neden olduğu çevre kirliliğinin önlenmesinde kullanılabilecek en önemli seçenektir. EA'ların şarjı için gerekli olan elektrik enerjisi, YEK'ler kullanılarak üretilirse küresel ısınmanın azaltılmasına katkı sağlanmış olacaktır **[10,11]** . Bu nedenle YEK ile elde edilen elektrik enerjisi ile çalışan EA şarj istasyonları günümüz EA piyasasında, sürdürülebilir kalkınmaya katkı sağlarlar **[36,39].** EA istasyonu amacıyla YEK ile ile üretim tesisi kurulması, 7.SKH'i destekler. EA istasyonu amacıyla YEK ile ile üretim tesisi kurulması, sürdürülebilir şehirler ve yaşam alanları hedefi (SKH 11) ve iklim eylemi (S13) ile eşleşir **[40]**. Şehirlerde kurulacak yenilenebilir enerji destekli EA şarj istasyonları, sera gazı emisyonlarının azalmasına ve hava kalitesinin düzelmesine katkı sağlar **[39].**

EA şebekeden şarj edildiğinde; gerilim regülasyonu, harmonik ve frekans regülayonu alanında sorunlarla karşılaşılabilinmektedir **[38].** GES destekli EA şarj istasyonu; enerjinin yerinde kullanımını ve şebekeden bağımsız olarak şebeke üzerinde olumsuz elektriksel olaylar yaratmadan enerji temini sağlar **[36].** GES destekli EA şarj istasyonları, Rüzgar ve HES gibi diğer YEK lere göre şehirlerde kullanım için daha uygundur.

FV GES lerin DC çıkışı, DC –DC hızlı şarj için daha uygun bir seçenektir. FV paneller EA ların DC şarjında yüksek stabilite gösterirler **[38].**

Türkiye'nin 2024-2026 dönemine ilişkin; hedef ve politikalarının yer aldığı OVP'de, EA'lar ile ilgili hedefler belirlenmiştir. Bu hedefler kapsamında; EA'ların yaygınlaştırılması için EA şarj istasyon ağının geliştirilmesi hedeflenmektedir **[34]**. Yapılan yasal düzenleme ile, EA şarj istasyonlarında tüketilen elektrik enerjisinin YEK'ler kullanılarak üretilmesi teşvik edilmektedir. Bu kapsamda, EA şarj istasyonunda tüketilen elektrik enerjisini YEK ile karşılayan EA şarj istasyonları, kullandıkları enerjinin tamamını Türkiye'nin ulusal yenilenebilir enerji sertifikası olan YEK-G ile karşılandığının belgelendirilmesi durumunda "Yeşil şarj istasyonu" olarak adlandırılmaktadır **[41]**.

5. Sonuç ve Öneriler

Türkiye'de binalarda tüketilen enerji miktarı, sanayide tüketilen enerji miktarından sonra ikinci sırada yer almaktadır. 2021 yılı toplam nihai enerji tüketiminin %31'i binalarda tüketilmiştir. Binalarda tüketilen enerjinin önemli bölümü fosil kaynaklar kullanılarak sağlanmakta olup, bina enerji tüketiminin yaklaşık %46'sı doğalgaz, yaklaşık %30'u ise elektrik enerjisi ile karşılanmaktadır. Binalarda tüketilen enerjinin önemli bölümü ısıtma amaçlı kullanılmakta olup, meskenlerin ısıtılması için gerekli enerji miktarı, meskenlerde tüketilen enerjinin %50-60'ı oranındadır.

Ukrayna – Rusya savaşı sonucu meydana gelen küresel enerji krizi, enerji arz güvenliğini, enerjide dışa bağımlılığı yüksek ülkeler açısından tekrar gündeme getirmiştir. Türkiye, birincil enerji arzında %78 dışa bağımlı bir ülke olup, doğalgazda %98, ham petrolde ise %91 oranında dışa bağımlıdır. Enerjide dışa bağımlılık Türkiye'nin dış ticaret açığını artırmaktadır. Türkiye'nin 2022 yılı enerji ithalat bedeli 96,5 milyar dolar'dır. Kalkınma planlarında yer alan Doğalgazın elektrik üretimi içindeki payını azaltma hedefine erişilememiştir. Hedeflenen doğalgaz oranın üzerinde doğalgaz tüketimi gerçekleşmiştir.

Binalardaki enerji tüketiminin daha verimli biçimde sağlanması, binalarda tüketilen fosil yakıtların azaltılması ve binalar kaynaklı sera gazı emisyonlarının azaltılması için YEK'lerden daha fazla faydalanılmalıdır. Binalarda elektrik enerjisi kullanımının artırılması ve bu enerjinin büyük oranda YEK kullanılarak sağlanması durumunda, sera gazı emisyonları ve enerjide dışa bağımlılık azalacak, cari açık düşecektir. Bina ısıtması için daha uygun fiyatlı, güvenilir ve sürdürülebilir enerji kaynakları kullanımı gereksinimini daha kaçınılmaz hale gelmiştir. Türkiye'nin 2053 yılı net sıfır emisyon hedefi kapsamında binalarda elektrifikasyon artırılmalıdır. Binalardaki ısıtma ve soğutma yenilenebilir enerjisi ile çalışan ısı pompaları ile sağlanmalıdır. Isı pompası verimlerinin ilerleyen yıllarda artması beklenmeketdir **[3].** Isı pompasının ekonomik açıdan tercih edilebilirliği, ısı pompası veriminin artması ve pompanın çalışması için gerekli elektrik enerjisinin YEK ile sağlanması durumunda artacaktır. Doğalgazda dışa bağımlılığı çok yüksek olan Türkiye için, başta bina ısıtması amaçlı olmak üzere yenilenebilir enerjisi ile çalışan ısı pompaları kullanımı enerjide dışa bağımlılığı azaltmak ve enerji arz güvenliğini sağlamak açısından da önemlidir. NSEB tasarımları yaygınlaşmalı, mevcut binalar enerji verimliliği yüksek olacak biçimde güçlendirilmelidir.

Ulaştırma sektörü nihai enerji tüketimi binalarda tüketilen enerjiden sonra en fazla enerji tüketilen sektördür. Türkiye'de 2021 yılı toplam nihai enerji tüketiminin yaklaşık %25'i ulaştırma sektörü tarafından gerçekleşmektedir. Ulaştırma sektörü enerji tüketimi içindeki petrol ürünleri payı % 98'dir. Ulaştırma sektörü nihai enerji tüketimi içindeki karayolu ulaşımı payı % 94'dür. Türkiye toplam sera gazı emisyonunun yaklaşık %15,5'u, ulaştırma sektörü kaynaklı oluşmuştur. Karayolu ulaşımı emisyonları, toplam ulaştırma sektörü emisyonlarının %95'ini oluşturmaktdır. Ulaştırma sektöründeki bu veriler dikkate alınarak, karayolu ulaşımındaki araçların elektrifikasyonu sağlanmalıdır. Ulaştırma sektörünün elektrifikasyonu, fosil yakıt tüketimini azaltacak, ulaştırma kaynaklı emisyonlarda ciddi azalış meydana getirecektir. Bu amaçla, öncelikle toplu ulaşım araçları kullanım oranı artırılmalıdır. İYM'li araçlardan EA'lara geçilmelidir. EA şarj istasyonlarının elektrik enerjisi talebi YEK ile üretilen elektrik enerjisi ile sağlanmalıdır. EA sayısının artması şehirlerdeki hava kalitesini iyileştirecek, gürültü kirliliğini önleyecektir.

Elektrik sisteminin dönüşümü ve elektrifikasyonun artması, fosil yakıt talebini azaltırken kritik minerallere olan telebi artıracaktır. Enerji sektöründe kullanılan temel kritik mineraller için pazarın büyüklüğü son beş yılda iki katına çıkmıştır ve büyümenin daha da artması beklenmektedir **[1].** Birçok temiz enerji teknolojisinin üretimi için hayati önem taşıyan kritik minerallerin tedarikine yönelik potansiyel riskler de bulunmaktadır. Kritik mineral madenciliği, işleme ve rafinaj yatırımlarının belirli bölgelerde yoğunlaşmıştır. Bu durum bir arz

güvenliği riski yaratmaktadır **[1].** Jeopolitik gerilimler, iklimsel etkiler, çalışma yaşamında karşılaşılabilecek sorunlar arz riski ortaya çıkarabilecektir. Politika yapıcılar, temiz enerji teknolojisi tedarik zincirlerinde oluşabilecek riskleri azaltacak tedbirleri almalıdır **[1].**

Artan elektrifikasyon ve oluşacak enerjisi talebinin karşılanması için, zengin YEK potansiyeline sahip Türkiye'nin başta GES olmak üzere YEK kurulu gücünü artırması gerekmektedir. Binalarda ve ulaşımda YEK dan daha fazla yararlanılması SKH hedeflerine ulaşılmasını destekleyecektir. Temiz ve katlanabilir maliyetli enerjiye erişilmiş olunacaktır. Sürdürülebilir şehirler ve topluluklar hedefi ile iklim eylemi hedefleri desteklenecektir.

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EMERGING TRENDS IN SMART BUILDING ENERGY MANAGEMENT: A COMPREHENSIVE REVIEW OF AI, IOT, AND SUSTAINABILITY ADVANCES

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ABSTRACT

This study examines the latest developments in Energy Management Systems (EMS) for smart buildings, which represent a significant step towards improving sustainability and efficiency in the constructed environment. The technique employed in this study entailed a rigorous examination of existing scholarly works, with particular emphasis placed on publications within the past five years to guarantee both pertinence and originality. The study uncovers noteworthy technical developments in the field of Emergency Medical Services (EMS), encompassing the incorporation of advanced sensors, Internet of Things (IoT) gadgets, as well as progressions in artificial intelligence and data analytics. These advancements have enabled the smooth integration of renewable energy sources, enhanced operational effectiveness, and improved user engagement and involvement. Significantly, the integration of artificial intelligence (AI) and big data analytics within the field of energy management systems (EMS) has brought about a transformative impact on energy optimization tactics, resulting in considerable reductions in energy consumption and environmental impact. The article additionally examines the difficulties encountered within this field, including technical intricacies, financial limitations, and regulatory concerns. The review examines prospective avenues for future research and development in order to anticipate forthcoming trends. It emphasizes the dynamic characteristics of smart building technologies and their significant impact on the formation of sustainable urban environments. The primary objective of this study is to provide valuable insights to researchers, practitioners, and policymakers regarding the current advancements in EMS for smart buildings. This emphasizes the significance of ongoing innovation and interdisciplinary collaboration within this domain.

Keywords: IoT; Energy Management Systems; optimization tactics; artificial intelligence

Introduction

Background

In the contemporary era of technological advancement and environmental consciousness, the concept of 'smart buildings' has risen to prominence. These structures, equipped with advanced technology, aim not only to provide comfort and convenience to their occupants but also to operate with a heightened sense of responsibility towards environmental sustainability. Central to achieving this harmonious blend of comfort and conservation is the role of Energy Management Systems (EMS). EMS in smart buildings are pivotal in orchestrating various aspects of energy usage – from heating and cooling to lighting and electronic devices. The importance of energy management transcends beyond mere cost savings; it embodies the urgent need to reduce our carbon footprint and combat climate change. Efficient energy management in buildings is crucial as they are one of the significant consumers of energy worldwide, contributing substantially to global energy use and associated greenhouse gas emissions.

Scope of the Survey

This survey zeroes in on the recent advancements in EMS, particularly focusing on developments within the past five years. This time frame is chosen to ensure the inclusion of the most contemporary technologies and strategies, reflecting the rapid pace of innovation in this field. The survey delves into various dimensions of EMS, including the integration of advanced sensors, the role of the Internet of Things (IoT), the application of artificial intelligence (AI), and data analytics. It also addresses the incorporation of renewable energy sources into EMS, a critical step towards sustainable energy practices. By examining these facets, the survey offers a comprehensive overview of the current state of EMS in smart buildings.

Objective

The primary objective of this survey is to furnish a detailed and nuanced understanding of the current advancements in EMS for smart buildings. It aims to bridge the gap between existing knowledge and ongoing innovations in this field. The survey seeks to provide valuable insights to researchers, practitioners, policymakers, and stakeholders who are involved or interested in the development and implementation of EMS. By highlighting recent technological advancements and discussing potential future directions, this paper endeavors to underscore the significance of EMS in driving efficiency, sustainability, and user engagement in smart buildings. The ultimate goal is to illuminate the pathways through which EMS can contribute to the creation of more sustainable, efficient, and intelligent urban environments.

Recent Developments in EMS for Smart Buildings

Advanced Sensors:

- **Role in Monitoring Energy Usage**: Sensors are the keystones in monitoring and managing energy usage in smart buildings. They collect real-time data on various parameters such as temperature, humidity, occupancy, and light levels. This data is crucial in making informed decisions about energy consumption and identifying areas for efficiency improvements.
- **Recent Sensor Technologies**: The recent advancements in sensor technology have been a game-changer for EMS. These include high-precision sensors, wireless sensor networks, and IoT-enabled sensors. These technologies offer greater accuracy in data collection, flexibility in deployment, and integration with other building systems. For example, the development of occupancy sensors that accurately detect human presence and adjust lighting and HVAC systems accordingly has significantly reduced energy wastage in unoccupied spaces.
- **Impact on EMS Accuracy and Efficiency**: Advanced sensors contribute to the enhanced accuracy and efficiency of EMS. They enable more granular control over building systems, leading to optimized energy usage and reduced operational costs. For instance, sensors that detect ambient light can adjust artificial lighting levels, thus saving energy without compromising comfort.

Internet of Things (IoT) Integration:

- **Contribution to EMS Effectiveness**: IoT integration takes EMS to a new level by enabling interconnectedness between various building systems and devices. This interconnectedness facilitates the seamless exchange of data, leading to more coordinated and efficient energy management.
- **Examples in Smart Buildings**: In smart buildings, IoT devices are used for various purposes like remote monitoring and control of HVAC systems, intelligent lighting systems, and energy consumption analytics. For instance, IoT-enabled thermostats can learn occupants' preferences and adjust the temperature accordingly, leading to energy savings. Additionally, IoT-connected meters can provide detailed energy usage analytics, helping in identifying patterns and potential areas for efficiency improvements.

Artificial Intelligence and Data Analytics:

- **Revolutionizing EMS**: AI and data analytics play a pivotal role in analyzing the vast amounts of data generated by sensors and IoT devices. AI algorithms can identify patterns, predict energy demands, and make real-time adjustments to optimize energy consumption.
- **Case Studies and Examples**: One notable example is the use of AI in predictive maintenance of building systems. By analyzing data from various sensors, AI algorithms can predict equipment failures before they occur, reducing downtime and saving energy. Another example is AI-driven energy analytics platforms that provide insights into energy consumption patterns, helping in identifying inefficiencies and suggesting corrective actions.

Integration of Renewable Energy Sources:

- **Challenges and Solutions**: Integrating renewable energy sources like solar and wind into EMS presents challenges such as variability in energy production and storage issues. EMS needs to be adept at balancing the intermittent nature of renewable sources with the building's energy demand.
- **Role of EMS in Managing Variability**: Modern EMS are equipped to handle these challenges by using predictive analytics to forecast energy production from renewable sources and adjusting energy consumption accordingly. For instance, on days with high solar energy production, the EMS can store excess energy in batteries or prioritize its use over non-renewable sources. Additionally, smart grid integration allows excess renewable energy to be fed back into the grid, optimizing energy usage and cost efficiency at a broader scale.

Challenges and Limitations

Technical Complexities

- **Integration and Compatibility Issues**: One of the primary technical challenges in implementing advanced EMS is ensuring compatibility and integration with existing building systems and infrastructure. Many buildings have legacy systems that may not seamlessly interface with modern EMS technologies. This can lead to challenges in data collection, communication, and control across different systems.
- **Complexity of Data Management and Analysis**: The sheer volume and variety of data generated by advanced EMS can be overwhelming. Efficiently managing, processing, and analyzing this data to derive actionable insights requires sophisticated algorithms and computing power. The complexity increases with the integration of AI and IoT, demanding more advanced technical expertise and robust data handling capabilities.
- **Reliability and Security Concerns**: As EMS become more interconnected and reliant on digital technologies, concerns about system reliability and cybersecurity become paramount. Ensuring the continuous operation of EMS and protecting them from cyber threats is a significant technical challenge, requiring ongoing vigilance and investment in security measures.

Financial Constraints

- **High Initial Investment**: Deploying sophisticated EMS often requires a substantial initial investment. This includes costs for new hardware (like sensors and controllers), software (including AI and analytics platforms), and system integration. For many organizations, particularly small to medium-sized ones, these upfront costs can be prohibitive.
- **Maintenance and Upgradation Costs**: Advanced EMS require regular maintenance and periodic upgrades to stay effective and secure. These ongoing costs, including software updates, hardware replacements, and technical support, can strain budgets over time.
- **ROI Uncertainty**: While EMS can lead to significant energy savings and operational efficiency, the uncertainty and variability in return on investment (ROI) can be a financial challenge. The time frame

to realize tangible financial returns from EMS investments can vary widely, making it difficult for stakeholders to commit.

Regulatory Issues

- **Compliance with Standards and Regulations**: Implementing EMS often requires adherence to a range of local, national, and international standards and regulations related to energy use, data privacy, and cybersecurity. Navigating these regulatory landscapes can be challenging, especially as they evolve rapidly with technological advancements.
- **Varied Building Codes and Energy Policies**: Building codes and energy policies vary widely across regions, adding complexity to the implementation of EMS. Compliance with these diverse requirements can necessitate customization of EMS solutions, increasing costs and complexity.
- **Data Privacy and Protection Laws**: As EMS collect and process large amounts of data, including potentially sensitive information, compliance with data privacy and protection laws becomes critical. This includes regulations like the General Data Protection Regulation (GDPR) in the European Union, which imposes strict rules on data handling and privacy.

Future Directions and Research Avenues

Potential Innovations

- **Advanced AI and Machine Learning Algorithms**: Future technological advancements in EMS are likely to be driven by more sophisticated AI and machine learning algorithms. These advancements could lead to more accurate predictive models for energy consumption and optimization, resulting in even greater efficiency.
- **Internet of Things (IoT) Evolution**: The ongoing evolution of IoT technology will further enhance EMS capabilities. Innovations may include more energy-efficient and powerful sensors, enhanced connectivity options, and the integration of IoT with other emerging technologies like 5G networks.
- **Energy Storage and Management**: Developments in energy storage technologies, such as more efficient batteries or new methods like hydrogen storage, could revolutionize how smart buildings manage and utilize renewable energy.
- **Blockchain for Energy Transactions**: Blockchain technology could be used to create more transparent and efficient systems for energy transactions, including the trading of renewable energy credits and peer-to-peer energy trading in smart grids.

Interdisciplinary Collaboration

- **Bridging Technology and Environmental Science**: Collaboration between computer science, engineering, and environmental science is crucial for developing EMS that are not only technologically advanced but also environmentally sustainable. This interdisciplinary approach can lead to a better understanding of how to balance energy efficiency with environmental impact.
- **Human-Computer Interaction (HCI)**: Incorporating insights from HCI can improve the user-friendliness of EMS interfaces, making it easier for building managers and occupants to engage with these systems effectively.
- **Integration of Architectural and Urban Planning**: Collaboration with architecture and urban planning can lead to the design of buildings and cities that are inherently more energy-efficient and better suited for advanced EMS.

Policy Implications

- **Incentivizing EMS Research and Development**: Policymakers can play a significant role by providing incentives for research and development in EMS technologies. This could include grants, tax breaks, or other financial incentives for companies and academic institutions.
- **Creating Standards for Interoperability and Data Security**: Developing and enforcing standards for interoperability between different EMS components and ensuring high levels of data security and privacy should be a focus area for policy intervention.
- **Supporting Renewable Energy Integration**: Policies that support the integration of renewable energy sources into the grid and EMS can accelerate the adoption of sustainable practices in smart buildings. This includes subsidies for renewable energy installations and policies that encourage the use of renewable energy sources.
- **Educational and Training Programs**: Investment in educational and training programs to develop a skilled workforce capable of designing, implementing, and maintaining advanced EMS is another area where policymakers can contribute significantly.

These future directions and research avenues highlight the dynamic and evolving nature of EMS in smart buildings, underscoring the necessity for continual innovation, interdisciplinary collaboration, and supportive policies to fully realize their potential in enhancing energy efficiency and sustainability.

Conclusion

This survey has provided an in-depth exploration of the recent advancements and future prospects in Energy Management Systems (EMS) within the context of smart buildings. The key findings underscore the significant strides made in integrating advanced sensors, Internet of Things (IoT) technologies, artificial intelligence (AI), and data analytics into EMS. These technological enhancements have not only improved the accuracy and efficiency of energy management but also facilitated the smoother integration of renewable energy sources, thereby contributing to operational effectiveness and sustainability.

The importance of EMS in the realm of smart buildings cannot be overstated. As the world grapples with the pressing challenges of climate change and resource conservation, the role of EMS in reducing energy consumption and carbon footprint becomes increasingly critical. Smart buildings, equipped with state-of-the-art EMS, stand at the forefront of this endeavor, showcasing how technology can be harnessed to achieve sustainability goals while maintaining, or even enhancing, comfort and functionality.

However, the journey towards optimal EMS is not without its challenges. Technical complexities, financial constraints, and regulatory hurdles present ongoing obstacles that need to be navigated. Despite these challenges, the potential of EMS in transforming energy use in buildings is immense, and the continued research and innovation in this field are vital.

Looking ahead, the survey highlights the need for interdisciplinary collaboration and policy support to further advance EMS technologies. Innovations in AI, IoT, energy storage, and blockchain, coupled with cross-disciplinary efforts and conducive policy frameworks, can accelerate progress in this field.

In conclusion, the advancements in EMS for smart buildings represent a confluence of technology, sustainability, and innovation. As the world moves towards more sustainable living practices, the continued evolution and adoption of advanced EMS in smart buildings will play a pivotal role in shaping energy-efficient, environmentally friendly, and intelligent urban habitats. Therefore, it is imperative to encourage and support ongoing research and innovation in EMS, ensuring that these systems continue to evolve in alignment with our sustainability goals and technological possibilities.

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GREY BOX APPROACH FOR ENERGY CONSUMPTION FORECASTING IN UNIVERSITY CAMPUS BUILDINGS

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ABSTRACT

Research conducted on building energy consumption forecasting contributes significantly to reducing energy costs, minimizing environmental impact, enhancing occupant comfort, and optimizing building performance. In this context, this study aims to enhance energy consumption forecasting in university campus buildings by integrating time series and physics/engineering-based datasets to develop a predictive model.

Methodology: The research integrates machine learning techniques by utilizing time series energy consumption data obtained from existing buildings alongside building physics/engineering data. Time series data for heating/cooling and lighting are combined with physics/engineering data, such as external environmental factors specific to the building, including outside air temperature, relative humidity, building floor area, floor height, and material type.

Results: The study discusses the success of energy consumption forecasting through a comparative analysis of time series and hybrid models. In contrast to models typically preferred in existing literature that focus on either time series or physical information, this research explores the relationship between the accuracy of predictions and the amalgamation of both data types.

Conclusions: This study represents a significant advancement in the field of energy consumption forecasting. The findings offer valuable guidance to energy managers and building owners in developing more effective strategies to increase energy efficiency and achieve sustainability goals. This methodology holds broader applicability, particularly in the context of complex structures like university campuses, within the realm of energy management.

Keywords: energy consumption prediction, grey-box approach, deep learning

Introduction

In buildings, energy efficiency and energy-efficient transformation are of great importance both environmentally and economically. Energy efficiency, in the context of increasing global energy demand and environmental issues, enables the more effective utilization of existing energy resources, thereby reducing dependence on fossil fuels. Additionally, energy efficiency contributes significantly to cost savings for building owners by lowering energy expenditures.

One of the primary causes of climate change is the carbon emissions released from energy sources derived from fossil fuels. According to 2022 data, building construction and related activities account for the largest share in both global final energy use (36%) and carbon emissions resulting from energy consumption (46%) (United Nations Environment Programme, 2022). Consequently, the building and construction sector plays a central role in efforts to reduce greenhouse gas emissions. Therefore, there is a need for further action to mitigate emissions and promote a low-carbon, sustainable built environment.

The aim of the research is to develop a predictive model for energy consumption in university campus buildings using machine learning techniques by combining time series data with physics/engineering-based datasets for

accurate energy consumption estimation. To achieve this objective, two research questions have been identified:

1. Do hybrid models, which integrate historical data, climate data, and building physical data when predicting energy consumption for existing buildings, outperform models based solely on past consumption data?
2. Do the results obtained from the comparison of these models demonstrate generalizability, comparability, and repeatability?

Literature Review

To measure and optimize the effects of energy-efficient transformation, it is essential to know the energy consumption of existing buildings first. The prediction of energy consumption is considered a fundamental element in the optimization process. In pursuit of this goal, various approaches can be found in the literature, exhibiting diversity in terms of data types, methods, and scales. Depending on the types of data used, studies predicting energy consumption in existing buildings can be classified into three main categories. Physical data-based studies focus on data related to physical characteristics such as building geometry, materials used, and user information. Historical data-based studies concentrate on data obtained through meters or sensors. Hybrid data-based studies, on the other hand, incorporate both physical and historical data (Khalil et al., 2022; Luo et al., 2020; Li and Wen, 2014; Aparicio-Fernández et al., 2019). Correspondingly, methods used in predicting energy consumption can be classified based on these data types. Historical data-based studies primarily focus on artificial intelligence and machine learning-based methods, while physical data-based studies often employ simulation-based methods. Hybrid data-based studies encompass a combination of these two approaches. Models in the literature are generally classified into three main approaches:

- White-box models: Models predicting energy consumption based on physical data.
- Black-box models: Models predicting energy consumption based on historical data.
- Grey-box models: Models that use both historical and physical data together.

Different methods are employed in the literature for predicting energy consumption (Bourdeau et al., 2019; Mlangeni et al., 2020; Chen et al., 2022). The methods highlighted in the scope of the research, depending on the nature and quantity of input data, are as follows:

- RNN; Long Short-Term Memory – LSTM and Gated Recurrent Units – GRU
- Random forest – RF
- Support vector machine – SVM
- Autoregressive integrated moving average – ARIMA

Various variables are used in predicting building energy consumption (Table 1). These variables encompass not only historical data but also building physical characteristics and user behaviors. However, the combination of historical datasets with static data is a crucial factor that can directly impact prediction accuracy. Merging two different types of data can lead to dimensional mismatches, missing or abnormal values, scale differences, challenges with multiple variables, and various inconsistencies in model selection and configuration, posing difficulties in data processing.

Despite these challenges, effectively integrating time-series and numerical data can provide valuable insights when handled accurately. To achieve a prediction model with high accuracy, appropriate preprocessing techniques, feature engineering, and suitable model selection are vital. Overcoming these challenges is a critical step in the development of energy consumption prediction models to enhance the reliability of analyses and forecasts.

Table 1. Variables Used in Predicting Building Energy Consumption

Authors	Description
Yalçıntaş 2006	Working hours, building age, gross area, annual electricity usage, lighting, air conditioning, percentage of electricity used for plug loads
Hong et al. 2013, Hong et al. 2014	Glass rate and type, roof type, heating-cooling degree and days
İbanoğlu 2014	HVAC systems, lightning systems, Electricity-consuming devices, building architecture, climate and environmental conditions, types of fuel used
Filik 2015	Building orientation, insulation, solar exposure, wind exposure, building form, length/depth ratio, height/length ratio, building height, roof type, roof slope, facade slope, facade transparency, building spacing, building shell and facade systems, active facades, amount and ratio of glass and windows, shading and sun control elements, interior design features, floor plan design, building use, per capita living or working area size, structural system design, walls, floor systems, building material, seismic resilience
Son et al. 2018, Cai et al. 2019 Dagdougui et al. 2019	Electricity consumption
Liu et al. 2019, Wang et al. 2020	Electricity consumption, heating and cooling loads

It has been observed that studies at the building scale are widely used for building energy management, improvements, and performance evaluations. These studies help assess the effectiveness of energy efficiency measures, identify areas with improvement potential, and optimize energy systems in a single building. On a campus scale, predictions are useful for energy planning, infrastructure development, and long-term energy management strategies for an entire campus or urban area.

The diverse advantages of using historical data to predict building energy consumption, such as data availability, ease of trend analysis, model calibration possibilities, and high prediction accuracy, have contributed to the widespread use of this data type. However, there are limitations to consider, including the absence of external factors, challenges in adapting to changing conditions, issues with data quality, and limited adaptability to changing circumstances.

To mitigate these limitations, complementing historical data with other data sources and employing advanced modeling techniques would be beneficial. Integrating different datasets and considering a broader context enhances the accuracy and robustness of building energy consumption predictions (Hu et al., 2022).

Materials and Methods

As historical data-based models do not require physical building information, they are more widely used compared to white-box models. However, in recent years, the integration of real measurement data with physical data has led to the perspective that grey-box models yield better results. To address gaps and challenges in the study, a model predicting energy consumption on a campus scale using historical and physical data sets, along with artificial intelligence techniques, has been developed. In this context, a workflow for creating the energy consumption prediction model has been defined (Figure 1). The acquisition of historical and physical data sets for the identified research area is planned first. Subsequently, suitable inputs for the model are prepared through the preprocessing process on the obtained data. The prediction model is then created by selecting models that best fit the nature of the data set, and the performance of the models is evaluated using appropriate performance criteria for model performance comparison.

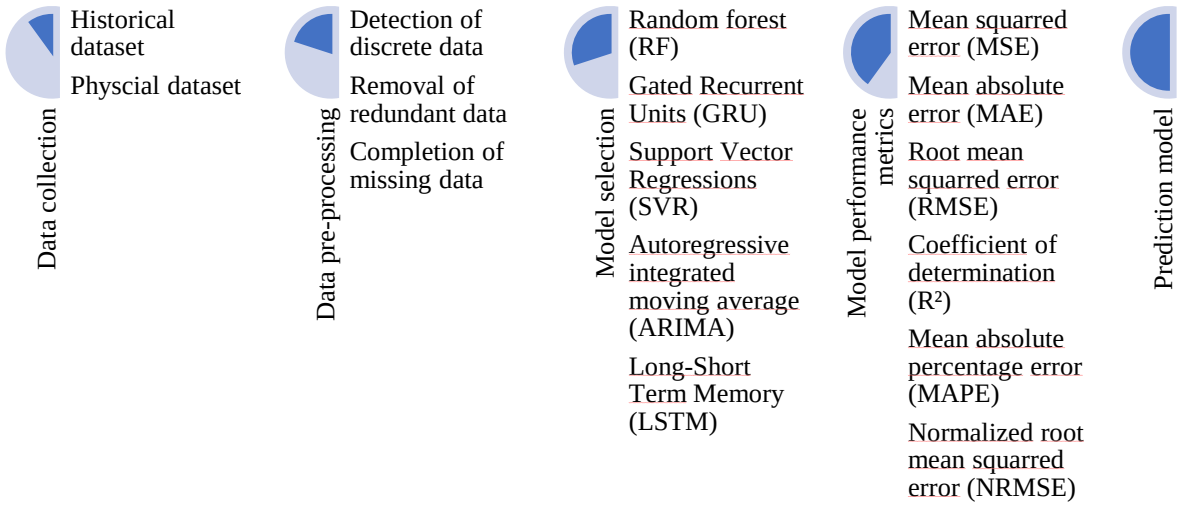

Figure 1. Flowchart of study

Study Area

As a result of literature review and examination of existing practices, it has been determined that studies are predominantly conducted at the building scale. The conclusion is drawn that studies at this scale may fall short in providing comprehensive approaches for the sustainable and energy-efficient transformation of existing buildings. In order to achieve holistic results about the proposed process design and sustainability approach and facilitate easy access to reliable data, Ankara University Beşevler 10th Year Campus has been chosen as the study area. Additionally, the historical characteristics, age, usage purpose, and diverse features of buildings within the campus allow for the comparison of study results and confirmation of their validity.

During the data acquisition process, it was not possible to obtain building-level consumption data since some buildings in the study area use shared electricity meters. Furthermore, due to some meters being of older types, daily data acquisition was not feasible and, therefore, was not preferred for use in the prediction model. To obtain campus-scale energy consumption predictions, four buildings representing different usage and construction techniques within the campus were utilized (Figure 2). Additionally, an abnormal change was observed in the electricity consumption data of one of the selected four buildings between July 2022 and September 2022. However, a concrete argument explaining this situation has not yet been formulated.

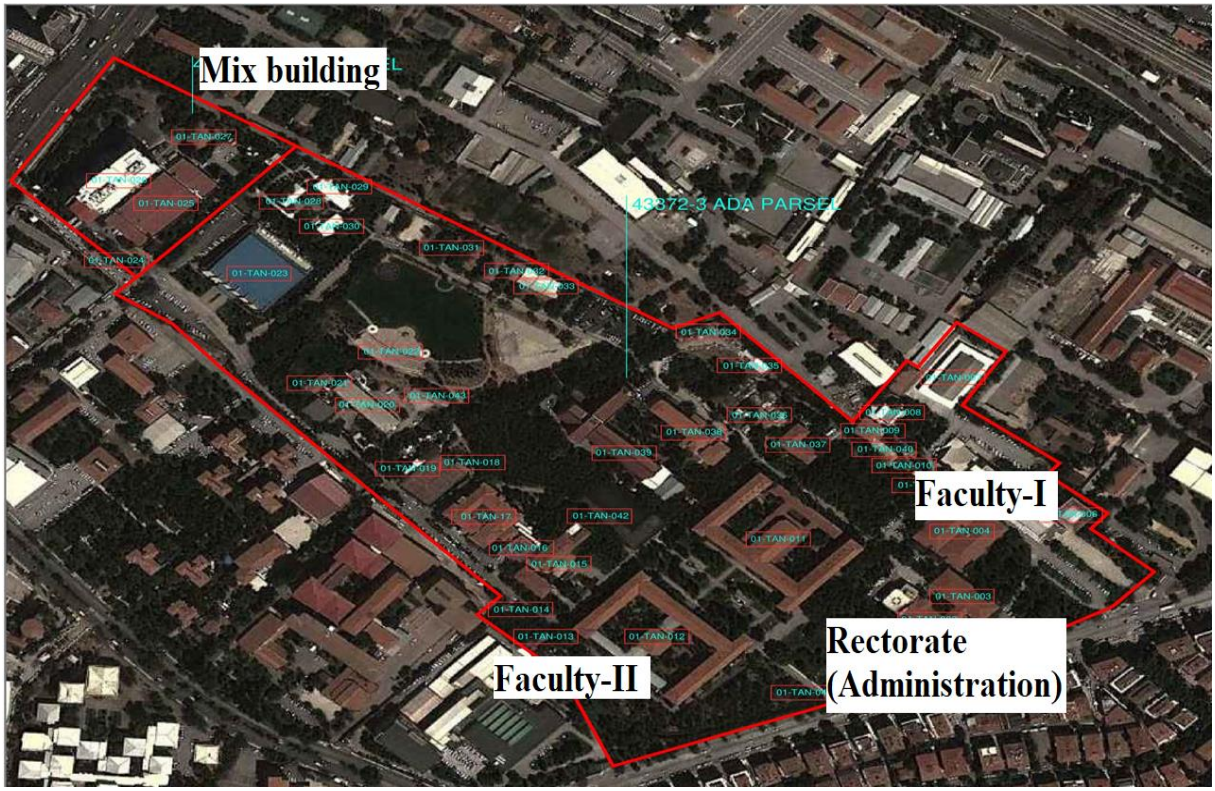

Figure 2. Selected buildings from the study area

Data

As part of the research, the combination of historical data and physical data related to the buildings is envisaged. Accordingly, the past electricity consumption data for the buildings, weather, and climate data for the location of the buildings, and the physical data for each building have been obtained from relevant data sources (Table 2).

Table 2. Types of Obtained Data and Data Sources

Data type	Level	Data source
Electricity consumption	Daily	Electricity distribution company
Weather and climate dataset	Daily	Turkish State Meteorological Services
Geometric and physical datasets of buildings	Categorical	Ankara University

Weather and climate data were obtained on a daily basis from the Ankara Youth Park measurement station measurements between January 1, 2021, and December 31, 2022. Within the scope of the research, data sets for vapor pressure, days with strong winds and storms, average snow height, average wind direction and speed, average temperature, average dew point temperature, average relative humidity, and total precipitation were obtained from the measurement station (Figure 3).

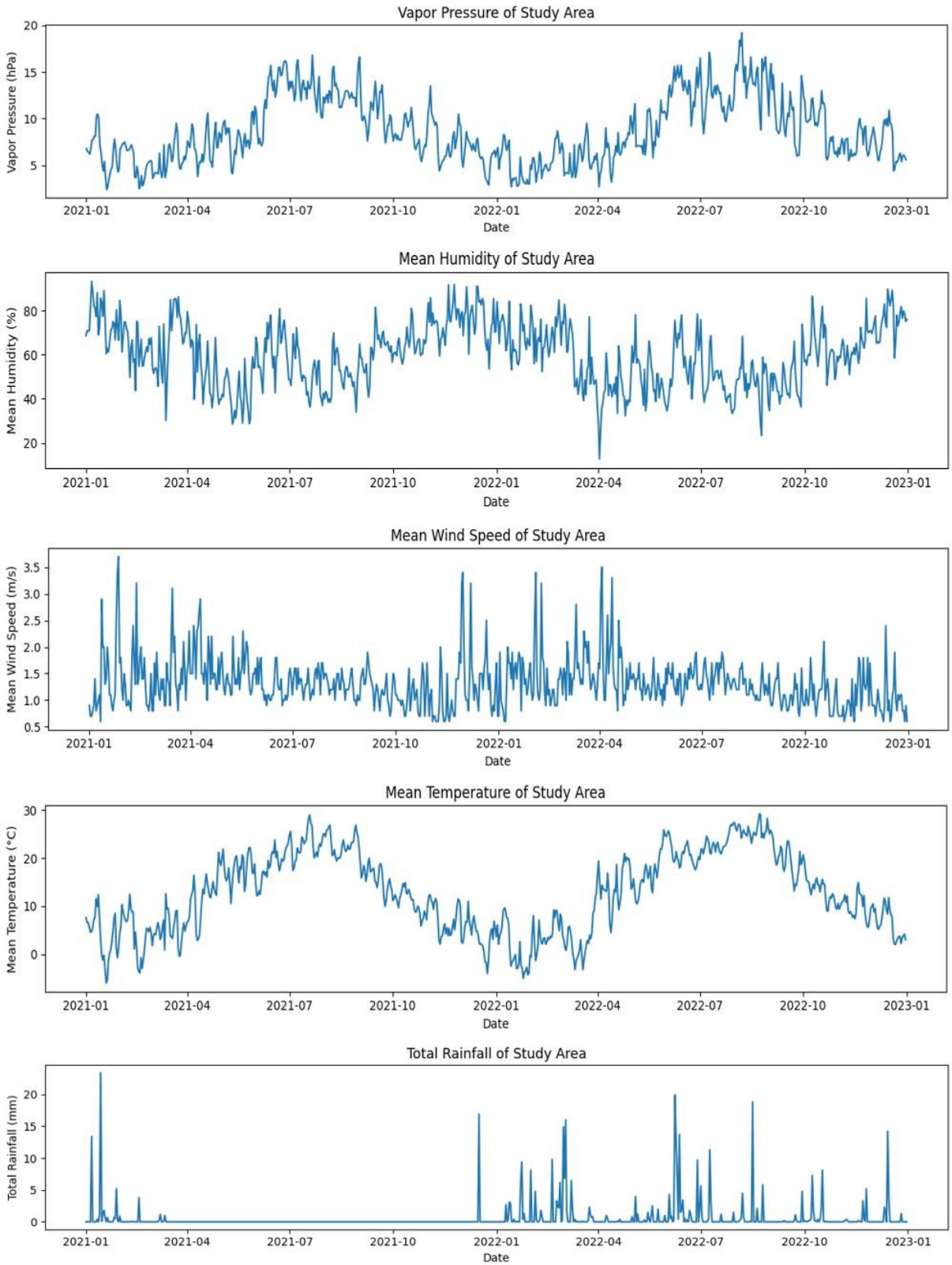

Figure 3. Weather and climate datasets of study area

When examining the collected meteorological data, it was observed that there were some missing values on several dates for vapor pressure, average temperature, and average humidity. The missing values were filled by comparing the data from the same period of the previous year with the values before and after the missing ones. No outliers were found in the data, and no data corrections were made.

Physical data for the selected buildings in the research area were obtained through architectural and static projects of the buildings. Considering the data titles obtained from the literature review, data such as building type (academic, administrative, mixed-use), building age, floor area (m²), length (m), height (m), depth (m), length/depth ratio (%), height/length ratio (%), glass ratio (%), glass type, roof type, and glass and window area (m²) were calculated for each selected building.

For obtaining the electricity consumption data of the research area, daily electricity consumption data were obtained from the electric meters of selected buildings between January 1, 2021, and December 31, 2022 (Figure 4). A data preprocessing process was conducted for the obtained data, and missing values were filled by considering the same period of the previous year and the values before and after the missing ones through interpolation. No outliers or repeated values were encountered (Table 3).

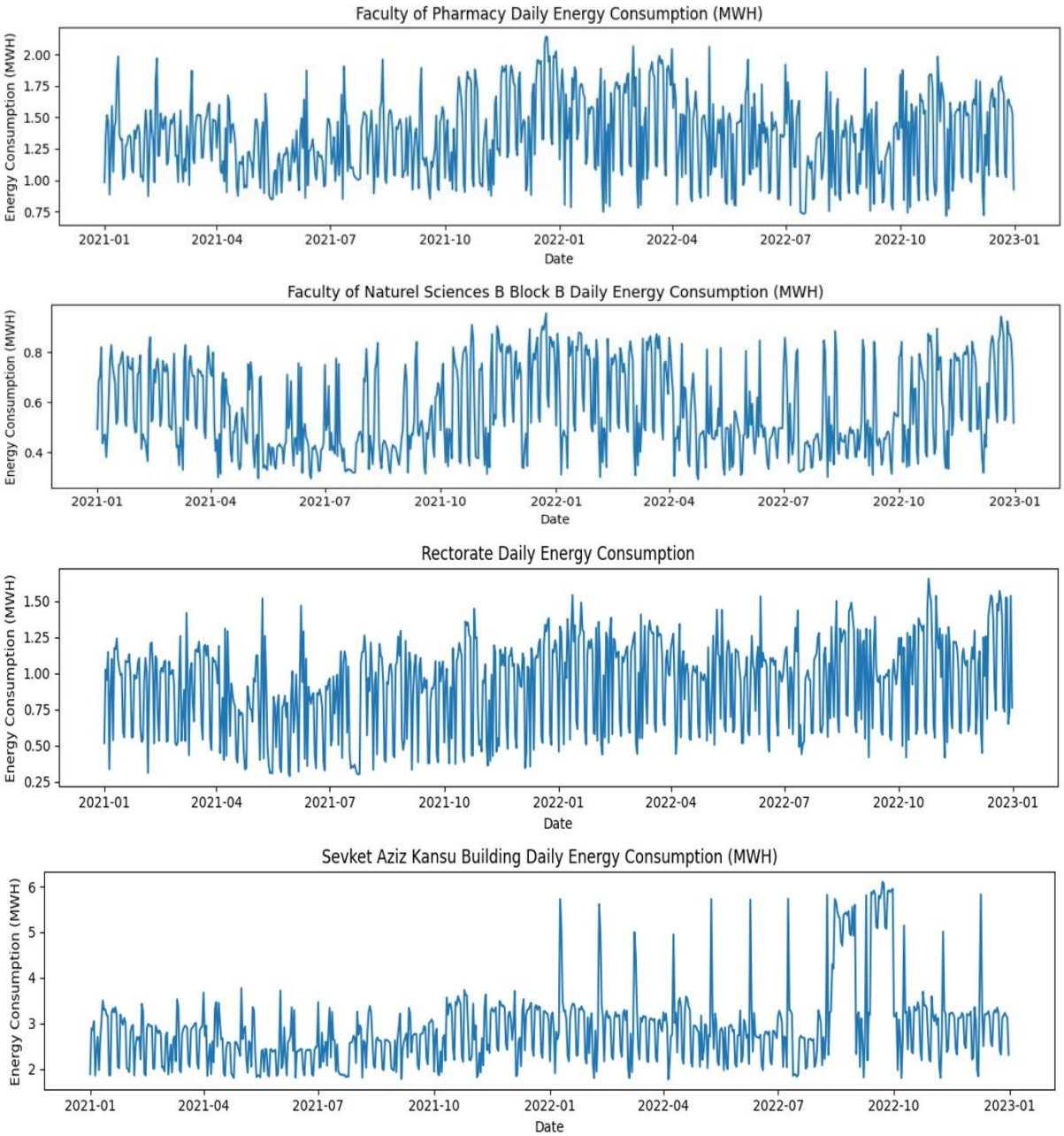

Figure 4. Daily electricity consumption dataset of study area

Table 3. Descriptive statistics

Parameter	Observation	Mean	Standard Deviation	Min	Max
vap_pressure	730	8.738	3.498	2.40	19.20
mean_wind_speed	730	1.325	0.467	0.60	3.70
mean_temperature	730	12.746	8.246	-6.0	29.20
total_rainfall	730	0.564	2.283	0.00	23.40
mean_humidity	730	59.724	14.182	12.70	93.30
Admin_electiricity_consumption	730	0.920	0.317	1.66	0.29
Mix_electiricity_consumption	730	2.893	0.868	1.77	6.10
Faculty_1_electiricity_consumption	730	0.568	0.177	0.29	0.96
Faculty_2_electiricity_consumption	730	1.346	0.323	0.72	2.14

After completing the data acquisition and preprocessing stages, the modeling phase was initiated. In this context, the obtained data types were collectively used in modeling studies through the following equation. Accordingly, the energy consumption data for each building, along with building characteristic features and climatic indicators of the research area, were represented in the model. The equation formulated for the modeling is as follows:

$y_it = \beta X_i + \gamma Y_t + \varepsilon_it$

y_it :Energy consumption amount of building type i on day t

X_i :physical characteristics of building type i

Y_t :climatic indicators of the campus on day t

ε : error amount

Findings and Discussion

In the study, results from the historical data set and the hybrid data set were compared based on performance metrics, considering the alternative where all selected buildings were used together. The GRU prediction model outperformed other models in terms of all performance metrics when a hybrid data set was used (Figure 5). RF and SVR models demonstrated consistent performance across different data sets, with minimal changes in performance metrics (Figure 6 and Figure 7). The ARIMA model showed lower performance, except for the MAPE metric when transitioning to a hybrid data set (Figure 8). The LSTM model, created using historical data, was found to be insufficient in explaining the data (Figure 9).

In the evaluation based on performance metrics; while the R^2 value was negative in LSTM and GRU models, it reached 0.99 in RF and SVR models. The MSE value was calculated between 0.004 and 1.345 for all models except the LSTM model (Table 4). The obtained results represent the evaluation of all selected buildings together and the assessment of all data in the data set. It is anticipated that evaluating buildings separately and using planned combinations in the data set can improve performance values. Sudden increases and decreases detected in the performance of the hybrid-used building are believed to impact the model's performance.

Table 4. Results of energy consumption prediction model

Performance metric	LSTM-historic	LSTM-mix	GRU-historic	GRU-mix	RF-historic	RF-mix	SVR-historic	SVR-mix	ARIMA-historic	ARIMA-mix
MSE	43.990	0	1.3448	0.0055	0.0043	0.0041	0.02501	0.0250	0.0979	0.1932
R^2	-374.2	0	-384.96	-0.5657	0.9958	0.9961	0.97588	0.9759	0.0640	-0.652
MAE	6.4654	0	1.1308	0.0634	0.0342	0.0340	0.08661	0.0866	0.2368	0.3608
RMSE	6.6325	0	1.1596	0.0739	0.0657	0.0638	0.15814	0.1581	0.3128	0.4396
MAPE	486.43	0	641.02	37.189	3.0487	3.0404	8.3684	8.3684	27.179	24.309
NRMSE	4.6544	0	4.7321	0.3014	0.0113	0.0110	0.0272	0.0272	0.2756	0.3085
MAD	6.4654	0	1.1308	0.0709	0.03415	0.0340	0.08661	0.0866	0.2368	0.3608

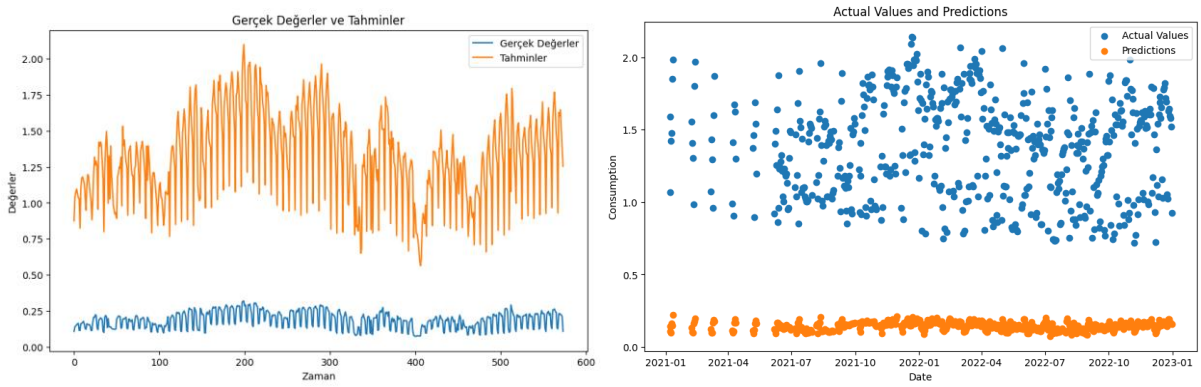

Figure 5. GRU historical and mix dataset model results

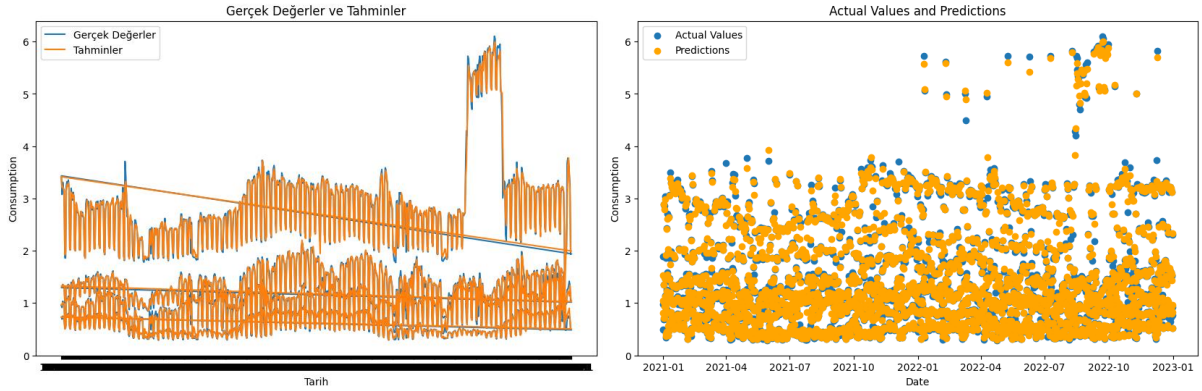

Figure 6. Random Forest historical and mix dataset model results

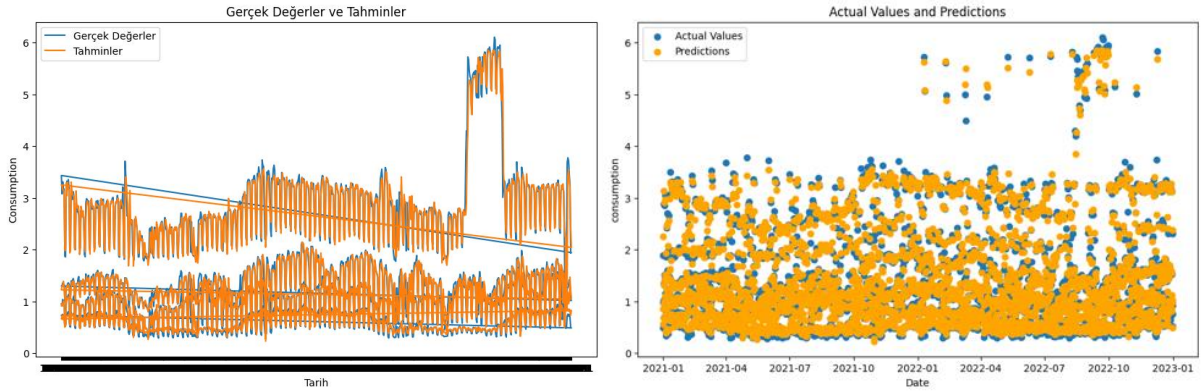

Figure 7. SVM historical and mix dataset model results

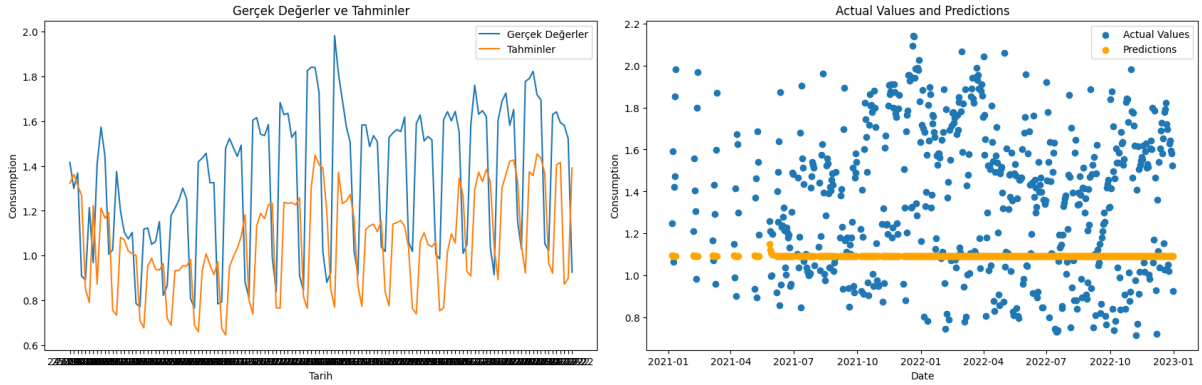

Figure 8. ARIMA historical and mix dataset model results

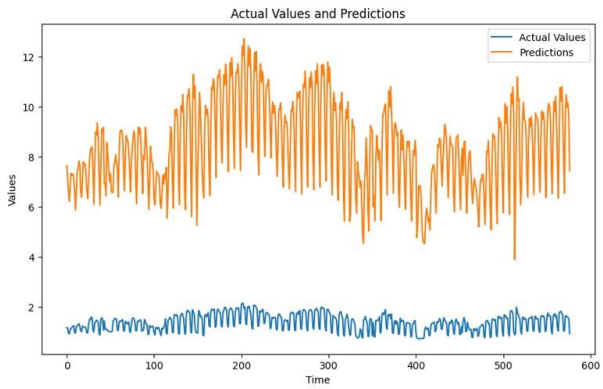

Figure 9. LSTM historical model results

Conclusion and Recommendations

Within the scope of the study, preliminary findings on energy consumption prediction using various methods have been shared. The analyses include a comparative evaluation of techniques such as LSTM, GRU, ARIMA, RF, and SVR. However, the results indicate that, except for RF and SVR, other methods did not achieve the desired performance. Therefore, it should be emphasized that the study is still in its initial stages, and further modeling work is necessary. Implementing improvement alternatives, such as dataset modification, feature engineering, model selection, hyperparameter optimization, model ensemble, performance metrics, and evaluating new approaches, in addition to evaluating individual buildings with data combinations, will enhance the performance of the energy consumption prediction model targeted in the study.

Using a more comprehensive and diverse dataset may increase the model's generalization capability. Exploring datasets from different time intervals may improve model performance. Identifying additional time series features or utilizing existing features more effectively could enhance prediction performance. For example, incorporating features such as trends, seasonality, autocorrelation, or external factors and applying advanced transformation techniques could be beneficial. Exploring different types or variations of models may increase prediction accuracy. Techniques such as hyperparameter optimization, trying different cell types, or experimenting with deeper architectures can be used in RNN-based models (LSTM, GRU). Fine-tuning the model's hyperparameters can improve performance. Using methods such as grid or random search to systematically explore hyperparameters or employing automatic hyperparameter tuning algorithms is recommended. Creating ensemble models by combining predictions from multiple models can help achieve better prediction performance. For example, combining Random Forest (RF) and Support Vector Regression (SVR) models may provide a more robust ensemble model. Evaluating different performance metrics can provide a comprehensive understanding of the model's performance. Considering not only error metrics (RMSE, MAE) but also appropriate metrics like accuracy, precision, and recall can be beneficial. Exploring new and innovative time series prediction methods, in addition to existing models, can contribute to advancements in the field. For instance, exploring deep learning-based transformer models or Bayesian methods could be valuable.

In conclusion, the study yields a range of outputs directed towards professionals and decision-makers in energy management, facility management, and real estate management, as well as policymakers, technology, and the economy. Modeling energy consumption accurately plays a crucial role in learning the trajectory of future consumption and reducing energy demand. It lays the groundwork for solving optimization problems aimed at reducing consumption in the fight against climate change.

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DETERMINATION OF OPTIMUM DC/AC RATIO FOR PV POWER PLANTS USING ARTIFICIAL INTELLIGENCE

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ABSTRACT

The trend towards renewable energy sources is increasing day by day due to increasing energy costs and environmental awareness. Solar energy, one of the leading and widely used renewable energy sources has become one of the indispensable sources of electricity production. To keep electricity production at the maximum level in solar PV power plants, the feasibility studies must be carried out correctly. Necessary evaluations should be made by considering the DC-installed power, the installation of the power plants, and their economic life. In this study, the importance of DC/AC ratio in solar power plants, performance problems in inverters which are of great importance for solar power plants (SPP), and the effects of losses in inverters on the power plant are explained. The configuration of the photovoltaic system, the dimensions of the inverters, the capacity of the PV array, and the clipped operating mode were examined, and the AC and DC plant conditions were commented on in the operation of the PV system. The output powers of the inverter and panels to be used are estimated using ANN. With this study, which tries to determine the DC/AC ratio more accurately, it is aimed to make investments more accurately. In this study, the importance of the DC/AC ratio in solar power plants, performance problems in inverters, which are of great importance for solar power plants (SPP), and the effects of losses occurring in inverters on the power plant are explained. Situations such as the configuration of the photovoltaic system, the dimensions of the inverters, the capacity of the PV array, and the cropped mode of operation were examined, and the AC and DC plant conditions were commented on the operation of the PV system. The output power of the inverter and panels to be used has been estimated using YSA. With this study, which tries to determine the DC/AC ratio more accurately, it is aimed to make investments more accurately. In addition, the performance of the PV power plant was evaluated with the results obtained.

Keywords: DC/AC ratio, photovoltaic panel, SPP, inverter clipping, inverter losses, ANN

Introduction

Renewable energy is among the most widely used energy sources in recent years. The determination of the DC/AC ratio has an important role in the studies to evaluate the performance of photovoltaic (PV) systems. In a solar system, as soon as the DC string produces more energy than the inverters can load, the inverter cuts off the excess power produced and limits the output power to the specified standards. This phenomenon is called the inverter clipping effect. Adding a new inverter to the system can be an alternative approach to reduce the inverter clipping effect and increase energy production. When deciding which scenario to implement, system designers should also consider the costs of purchasing and installing an additional inverter to the system to compensate for the energy lost due to the inverter outage if they overgrow the solar array. The lowest DC power that can be connected to an inverter should be half of the inverter power. Under normal conditions, this value usually varies between 130%-136%. The highest power value that can be connected is determined from the inverter catalog and is usually between 130% and 150%. DC/AC conversion efficiency in grid- connected photovoltaic; (PV) systems depends on various factors such as the climatic characteristics of the site (especially solar irradiation, ambient temperature, and wind speed), the technological characteristics of the selected inverter, the PV module technology, the orientation and slope of the PV generator, the array-to-inverter power sizing ratio, and the DC input voltage fed to the inverter. depends [1]. Simultaneous analysis of all these factors

is not only necessary to know the on- site performance of a particular inverter subject to a PV configuration and adapt to other possible alternatives but also an important step for sizing a grid-connected PV system and estimating the final energy efficiency of the installation. It has been found that AC components will wear out faster if the inverters cut the output power on the AC side. For this reason, the maximum DC/AC ratio should be checked while installing the solar power plant. Aguascalientes analyzed the DC/AC energy conversion efficiency of grid-tied PV inverters in the low-latitude semi-desert climate of México [1]. The methodology developed for optimum inverter loading ratio (ILR) was applied to one full year of solar power generation data for five technologies. For inverter loading rates (approximately 120%), which are commonly used in grid-scale PV plants, the overload losses vary between 0.3% and 2.4% depending on the technology [2].

Materials and Methods

With the development of PV technology, it started to become widespread first in homes and then in factories and industrial establishments. The rapid growth of PV power generation facilities is due to the development of modules, inverters, and transformer technologies and the corresponding decrease in prices. This decrease has a positive effect on the performance of PV plants [3]. Thanks to the developing technology and software and numerical analysis, time series performance analyses of photovoltaic systems are completed through simulations. Analysis of the power curve of PV systems affects system design, system integration, and system performance. A linear power curve-based model is proposed to compare different inverter models without the need for many simulations [3]. In a study, cost values were analyzed and the DC/AC ratio was optimized [4]. While Faranda used a linear graph for the monthly time curve, he used a quadratic distribution curve for the hourly curve.

In terms of project costs, the DC/AC ratio is one of the most important parameters to be defined [5]. In a Grid-On system, it is tried to obtain maximum energy and performance from every part of the system to reduce the cost of inverters [6][7][8]. Smaller sizing of the DC/AC ratio than PV is a possible solution to improve system performance and reduce costs, but there is no consensus to calculate the exact ratio between the rated power of the inverter and the PV plant. In Europe, the optimum performance of the PV system for a grid-connected system is achieved for an inverter size of 0.6–0.7 times the PV-rated capacity [9].

Table 1. Symbol- Quantity

Symbol	Quantity
η	efficiency
AC	alternating current
DC	direct current
kw	kilowatt
kWh	kilowatt-hour
P	power (kW)
PV	photovoltaic
ηinverter	efficiency of inverter
Eclipped	DC energy (kWh) is potentially generated by the PV array but not converted into AC because of the inverter size
Eproduction	Annual energy production (kWh) based on rated power and capacity factor (before inverter clipping)
Pactual	The actual power output of a PV system (kW)
Pinverter	rated capacity of an inverter (kW)
PR	Performance Ratio

1.1. Determination of DC/AC Ratio

Solar cells generate direct current (DC) electricity, which is then converted into alternating current (AC) electricity by an inverter. Converting energy from DC to AC allows you to transmit it to the grid or use it to power buildings, both of which run on AC electricity. When designing a solar installation and choosing an

inverter, it should be considered how much DC power will be generated by the solar array and how much AC power the inverter can produce (power rating).

In this article, some important aspects of solar energy projects are addressed to ensure that the inverters in the designs are of the appropriate size. Specifically, the relationship between the amount of energy produced by the solar panel and the amount of power that the inverter can produce is examined and the concept of inverter clipping is defined. Generally, the DC/AC rated power of the inverter to be used in the PV system is selected as equal to the total nominal power of the system. This selection criterion is often not sufficient to meet the optimum needs of the systems. Environmental factors such as ambient temperature, wind, and radiation intensity can be shown as the reason for this. Contrary to popular belief, high temperature, and radiation do not cause a higher power output. The amount of radiation and temperature affects the performance of the inverter. Therefore, the size of the inverter may not be fully determined. For the optimization of inverter size, in-depth analyses should be carried out considering the effect of various factors.

1.2. When Does Cropping Occur on the Inverter?

By enlarging the inverters used in solar energy systems, the system can produce excess energy, but this method can be costly. When the DC maximum power point (MPP) or the point at which the solar energy array produces the most energy is greater than the power value of the inverter, the "extra" power produced by the array is truncated. Figure 1 also shows an effect called inverter cropping.

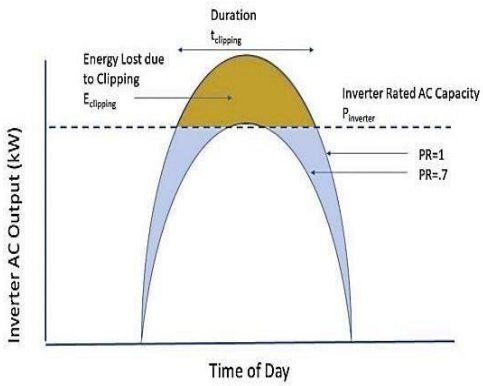


Fig. 1. The conceptual diagram showing the time duration of the daily power profile shows the trimming and production loss for two different levels of DC plant performance by inverter capacity (AC) (PR = 1 and PR = 0.7).

Recently, when determining the DC/AC ratio in STC, optimization is carried out over the nominal power of the inverter. With these processes, maximum energy is targeted. To make the maximum kWh/kwp value in solar energy projects, it was among the general assumptions to choose the DC/AC ratio in the range of 1.00 – 1.20. Today, there are inverter manufacturers that allow installations with a DC/AC ratio of

1.75. When determining the optimum ratio for the system, attention should be paid to the network connection rules. With the short circuit that may occur by choosing a high DC ratio, the amount of current to be transferred from the panels to the inverter also increases. The inverters to be used must be selected by the short-circuit current [10]. The production values corresponding to the values of 1.1 and 1.4 of the DC/AC ratios shown in Figure 2 are shown. The figure shown just below the low-radiation figure shown in the graph is given as the graph of the high-radiative day.

Simulations were conducted in different project configurations, different climate zones, different technologies, and different plant layouts where the DC-AC ratio varies between 100% and 150%. Further analyses were also carried out to assess additional parameters such as the modules' annual power drop, plant life, or reactive power control needs. The technical limitations and/or limitations and/or disadvantages associated with the increase in the DC-AC ratio were considered in simulations/analyses to suggest a complete and realistic study with valuable results and to find the best balance. Moreover, in the case of a

limited usable area, the methodology allows for optimization of the reduction of the number of inverters and the associated fixed cost without a critical impact on production and related revenues. Ultimately, this work leads to a powerful method and efficient tools that allow estimating the optimal DC- AC ratio specific to the project at the preliminary design stage, considering local characteristics and financial information available at the time.

Oversizing a solar array according to the degree of an inverter (DC/AC ratio of more than one) allows for increased energy harvesting over a large part of the day, especially in the mornings and afternoons. The ratio of DC to size AC has fallen below 1.5. Designers size inverters in a way that minimizes the lifetime cost and knows and accepts crop loss, but they also consider other constraints such as transformer capacity and the maximum values imposed by AC mains interconnection, to smooth the network integration (less fluctuation in output) and allow for more hosting capacity in a network, the ratio is set to a certain value DC/AC < 1.42 should be under [11].

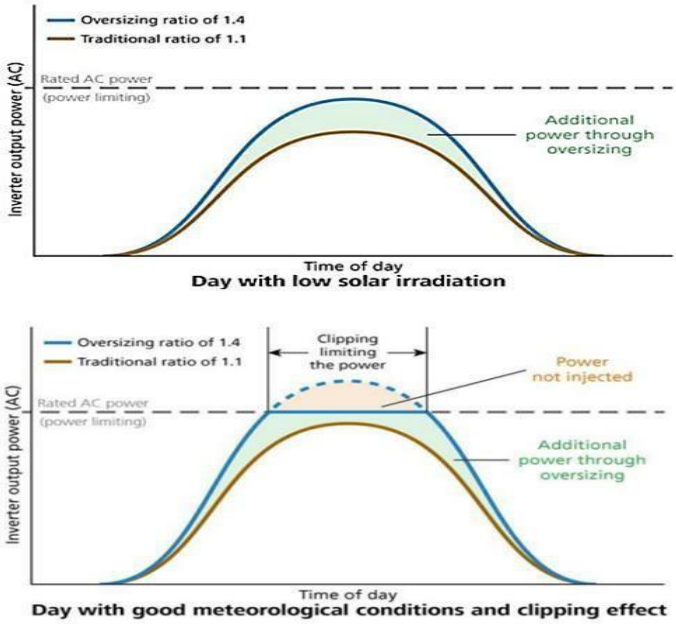


Fig. 2. Comparison of two different DC-AC ratios on a low- radiation and high-radiation day. Two days when there is no power limitation (figure above) and when it is (figure below)

1.3. Theory and Calculations

This paper looks at the effect of inverter clipping over a typical day and uses a time curve-based analysis to measure the effect of inverter clipping on annual performance ratio estimates (PR), an important performance indicator that is commonly used. It measures the performance of PV systems and compares system performance with measurements performed over different periods. The inverter is evaluated by integrals for the energy "trimmed" according to its size and the power transmitted to the receiver.

It will be more difficult to measure the energy lost because of trimming because the clipping is achieved by subtracting the array voltage from the optimal MPPT value and there is no power measurement to be done directly related to cropping. With high DC/AC ratios above one, the available energy increases early and late in the day. However, the result is that the inverter is cut off from time to time above the maximum energy distribution attached to the contract. This limitation is an application in which DC capacity is increased to develop additional energy production, where inverter saturation occurs above the trimming line. In addition, cropping is also affected by depreciation from temperature, which is another factor that must be considered. Still, the amount of energy lost because of clipping can be estimated by comparing the actual output with a model prediction of what would happen without the trimming, and perhaps normalizing this to the expected energy to calculate a performance ratio. The hours spent trimming will be inversely proportional to the decrease in performance.

It is very important to properly design a system with a DC-to-AC ratio greater than 1, as well as to model frequent inverter clipping in regions with radiation greater than standard test conditions (STC) of 1000 W. If the system is designed to have a DC-to-AC ratio of 1, it will never be cropped; however, the ac capacity of the inverter is also not fully utilized.

If a larger system size is desired, another 100-kW block (a portion of solar panels connected to the inverter) can be placed or more DC power generation can be packaged into the first inverter.

Table 2. DC/AC ratio

DC- to-AC Ratio	Annual AC Energy Production	Energy Lost to Clipping
1.0	163.06 MWh	0.0 MWh
1.3	193.86 MWh	1.8 MWh (0.9%)
1.5	217.24 MWh	11.0 MWh (4.8%)

Table 2. summarizes how much energy is trimmed for the inverter system, as well as the power generation results for the three DC-AC ratios. If a simulator does not model cropping properly, the designer may be led to believe, for example, that a 100-kW inverter can fully handle a DC/AC ratio of 1.5 MWh and an output of 786 MWh, whereas it will be 400 MWh. This can lead to a system that performs poorly based on the expected outcome. Knowing how much energy is being cut off allows a designer to understand how effective the oversizing scheme is in increasing energy harvesting and determine which system configuration is most cost-effective to make an informed decision about how much DC power to connect to the inverter. The number of inverters will be affected by all cost calculations of wiring.

The scanned areas shown in Figure 3. are a,b,c;

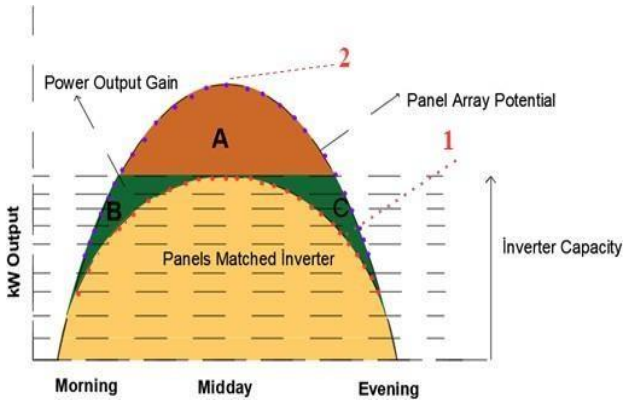


Fig. 3. Drive AC output for one day for a system with a low DC-AC ratio (red curve-1) and a high DC-AC ratio (purple curve-2). The painting represents an idealized situation; In practice, the power output varies significantly depending on weather conditions.

b+c > a……profitable situation, investable

b+c < a……loss situation, no investment

b+c-a……...feasibility period

The energy that cannot be converted at first is called clipped energy, but the amount of AC energy that cannot be transmitted must be defined because the AC power output to be transmitted to the system is limited by a smaller inverter [12] (Fig.4). This situation will soon concern the design of the system. The integral of power (kW) exceeding the inverter capacity (kW) is evaluated by Equation 1 and Equation 2 as follows:

$$E_{clipped}=\int_0^{tclipped}(P - Pinverter)dt \qquad (1)$$

$$E_{clipped}=\int_0^{tclipped}\left(PR\ Prated\ (1-(\frac{t}{AT})^n\right) - Pinverter)dt \qquad (2)$$

kWe shows the inverter power, kWp shows the panel power. The parameter to be decided in the system is kWp. kWe should consider the losses in Figure 4. to switch to kWp, but with those losses, the curve that is usually used to get more income from the investment should be brought up. The inverter must be able to load up to 1.5 times its own.

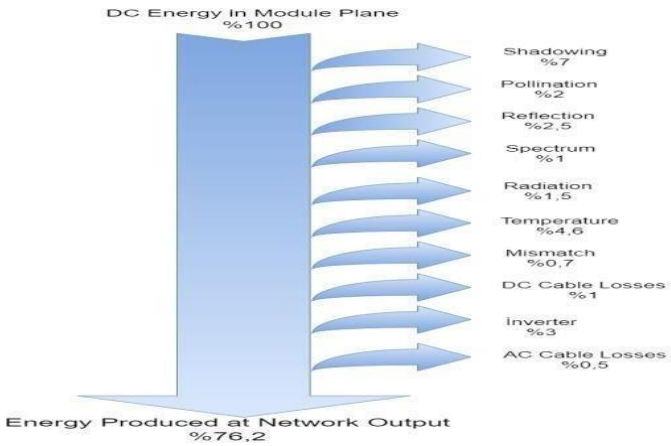


Fig. 4. Energy Losses

Inverter clipping or inverter saturation occurs when the DC power coming in a photovoltaic panel exceeds the entry-level maximum of the inverter. To reduce the input power of the inverter in the system, DC voltage adjustment is made by increasing the voltage and decreasing the DC. Inverter clipping has been shown to occur when the DC/AC ratio is greater than 1.4 [13].

Solar power plant designers should evaluate the crop ratio based on the DC/AC ratio in terms of system production capacity and performance.

2. Simulation Model

Estimation studies were carried out using AC and DC parameters of a GES system. With the DC generation information to be provided from the system, the determination of the contract power and the DC/AC ratio, and the rate at which the system works more efficiently were commented and PR (performance Ratio) was evaluated.

Fig. 5 gives a 10-day production curve for October. Estimation studies were carried out using these values (Fig 6.)

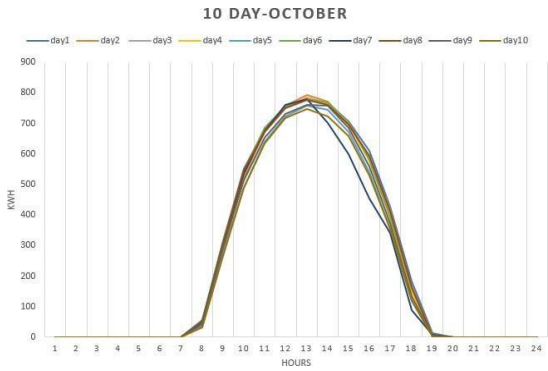


Fig. 5. 10-day production curve for October practice, the power output varies significantly depending on weather conditions

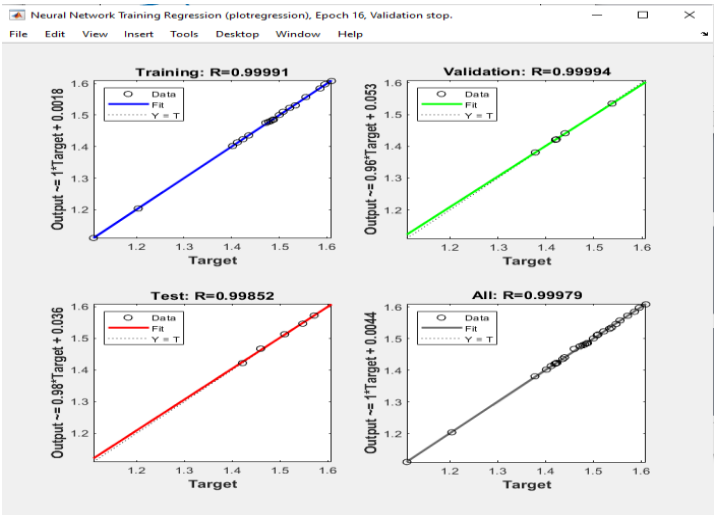


Fig. 6. Production forecast charts for October.

Considering the production data for October, the DC/AC ratios obtained are shown in Fig 7.

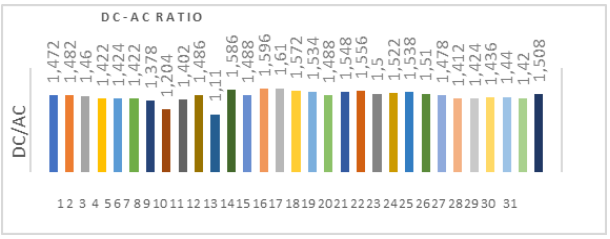
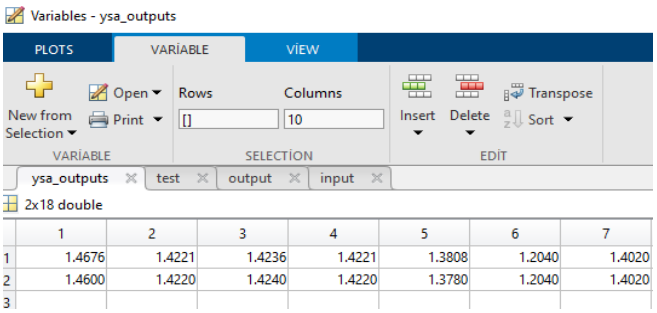


Fig. 7. 31-day DC/AC Rate for October.



	1	2	3	4	5	6	7
1	1.4676	1.4221	1.4236	1.4221	1.3808	1.2040	1.4020
2	1.4600	1.4220	1.4240	1.4220	1.3780	1.2040	1.4020
3							

Fig. 8. Actual value vs. forecast for October.

3. Conclusion and Recommendations

Sizing the DC/AC inverter smaller than the rated PV array is often the recommended solution to improve the performance of the entire system and reduce its costs. The power trimming of the inverter first reduces the overall efficiency of the system. Second, if trimming occurs frequently, it can reduce the service life of the inverter and potentially damage the panels or other components of the system. When a DC array produces more energy than the inverter can handle, the inverter cuts off the excess power and limits its output to its rated power (an effect known as inverter clipping). An alternative approach to increase energy production while avoiding an inverter outage might be to add another inverter. When deciding which approach to choose, designers must consider the balance between the cost of purchasing and installing an additional inverter compared to the value of energy that would be lost due to an inverter outage if they overgrown the solar array. However, if the output of the PV panels exceeds the maximum power capacity of the inverter, the excess power will not be converted into AC electricity but will instead be "trimmed" or limited. The maximum power output of your solar panels must be accurately estimated, this information is usually available from the panel manufacturer. It is important to have an accurate estimate of the maximum power output to determine the right size inverter for the system. When estimating the energy production of a solar project design, your performance simulations must take inverter trimming into account to ensure that the production results accurately reflect the system size of the design. If the inverter cuts off the output power from the AC side, field experience shows that the internal AC components will wear out faster. However, overloading the DC side of these inverters can void the warranty, so installers should check the maximum DC/AC ratio in the manufacturer's datasheet. The array and central inverters will be self-limiting to protect the internal components, but the designer needs to keep the array input voltage below the inverter's maximum limit. In addition, the maximum short-circuit current of the system must not exceed the rating of the driver or the maximum power rating of DC components such as terminals, busbars, and MPPTs. As the contractor adds more modules to a stationary power inverter, midday production on high-radiation days will maximize the inverter's AC output rating, with extra production in the mornings and afternoons. If there are advantageous end-of-use electricity rates, designers can adjust the azimuth angle of the array as another strategy to optimize energy production late in the day by increasing the system's IRR. According to the study, if the central or array inverter is the type that "cuts" the PV power on the DC side to protect against overload, there is a wide range of options that solar designers can offer. Plumbers must take advantage of inverter trimming to accomplish the different goals of their solar installations, from residential rooftops to utility-scale solar farms. The maximum power output of your Solar panels must be accurately estimated to avoid interruption in the inverter-based solar system. This information is usually available from the panel manufacturer. An inverter with a capacity exceeding the estimated maximum power output of the PV panels should be selected. Individual panel production must be viewed in real time to see how each panel is performing. The DC/AC ratio is the most important economic variable of a solar power plant investment. It affects both the initial investment and the return on energy. Therefore, this study was carried out to contribute to the optimum determination of the DC/AC ratio. According to this study, DC/AC being in the range of 1.25-1.4 will provide more benefits to the investor in terms of economy.

In this study, the importance of the DC/AC ratio in solar power plants, performance problems in inverters, which are of great importance for solar power plants (GES), and the effects of losses occurring in inverters on the power plant are explained. Situations such as the configuration of the photovoltaic system, the dimensions of the inverters, the capacity of the PV array, and the cropped mode of operation were examined, and the AC and DC plant conditions were commented on the operation of the PV system. The output power of the inverter and panels to be used has been estimated using YSA. With this study, which tries to determine the DC/AC ratio more accurately, it is aimed to make investments more accurately. In addition, the performance of the PV power plant was evaluated with the results obtained.

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REDUCED HARMONICS IN A SEVEN LEVEL ASYMMETRIC MULTILEVEL INVERTER WITH APERIODIC DC SOURCES

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ABSTRACT

Nowadays, multilevel inverters are mostly used in industrial applications. Cascade H-Bridge structure is one of the multilevel inverter topology for converting DC to AC. While achieving this operation, if DC sources used with different ratios, it is called Asymmetric Multilevel inverter. Lots of different fault types can be accrued in the operation of inverter. One of this fault is caused by decreasing of the DC source. When this fault occurs, the output wave of the inverter will deviate from the sinus form due to harmonics. To correct this situation, it is necessary to make changes to the multi-carrier PWM modulation used to generate the switching signals of inverter. In this study, it is aimed to reduce the total harmonic distortion in the output wave by using multi-carrier PWM modulation in case of decrease in one or both of the DC sources in the seven-level Asymmetric multi-level inverter.

Keywords: Aperiodic DC Sources, Multilevel Inverter, THD

Introduction

Inverters are crucial components in a wide range of applications, from powering electronics to enabling renewable energy. To meet the specific requirements of each application, researchers have developed different types of inverters, each with its own advantages and disadvantages. Inverters has two different basic types; traditional (2 Level) inverter and Multilevel inverter (MLI). MLIs achieves more level at the output of inverter for reducing ratio of dV/dt and total Harmonic Distortion (THD). MLI is sectioned three topologies; Diode clamped MLI, Flying capacitor MLI and Cascaded H-bridge (CHB) MLI. CHB MLI requires fewer components, less complex control mechanisms but needs more DC sources than other topologies. [1,2]

CHB MLIs are classified symmetric and asymmetric about DC sources. DC sources of symmetric MLI are equal value. The asymmetric topology includes unequal DC sources that the ratios of sources value designed as a power of two (binary) or three (trinary) and named as Asymmetric Cascade MLI (ACMLI). Sources in ACMLI is increased periodically. The following Equations (1) and (2) are calculate the output voltage level for binary structure and trinary structure. Here, “N” is the output voltage level and “m” is the cell number in (1) and (2), where the “x” parameter is an integer. [3-5]

$$N_{binary} = 2^{m+1} \rightarrow V_{DC} = V / 2^{x-1}, | x = 1,2,...,m | \tag{1}$$

$$N_{trinary} = 3^{m} \rightarrow V_{DC} = V / 3^{x-1}, | x = 1,2,...,m | \tag{2}$$

The ACMLI topology achieves that more output level while less number of switching device. CHB MLI topology are shown in Figure. 1. Voltage sources in Figure. 1 (V1, V2, … ,Vn) must be selected belong to the type of topology. ACMLI topology with binary mode is used in this study. For a seven level MLI, there must be two source and two H-bridge cell in structure [6-9].

Figure 2 is depicted the voltage levels of seven level ACMLI’s. While the source voltages are applied as VDC and 2VDC, the output levels are +3VDC, +2VDC, +VDC, 0, -VDC, -2VDC, -3VDC. [6,9]

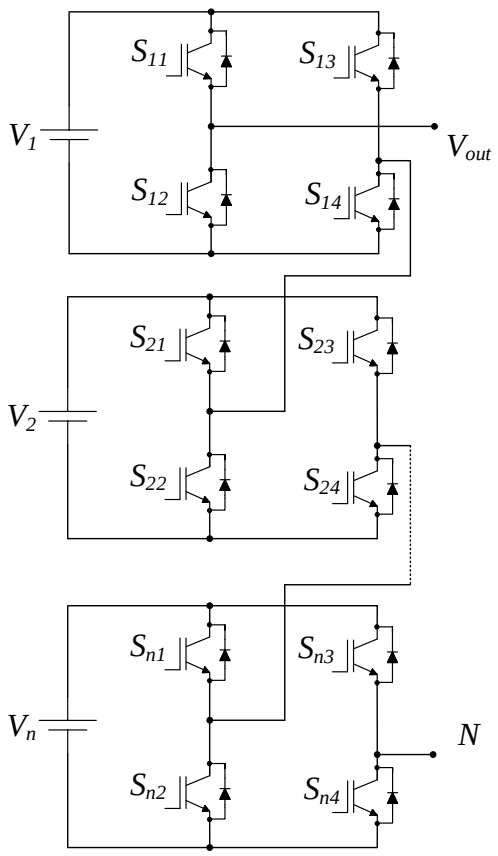

Figure 1. CHB MLI topology

MLI topologies use many modulation techniques for achieving the output levels. Best known of these modulation techniques are Space Vector PWM (SVPWM), Selective Harmonic PWM (SHE-PWM) and Multi Carrier PWM (MC-PWM) which are mostly used in MLI topologies. One sinusoidal signal is compared with triangular signals in MC-PWM method. The number of triangular signals are one minus from level of the MLI. Configuration of the triangular signals change the methods of MC-PWM those are Phase Disposition PWM (PD-PWM), Phase Opposition Disposition PWM (POD-PWM), Alternate Phase Opposition Disposition PWM (APOD-PWM) and Phase Shifted PWM (PS-PWM) methods. [10-12]

With the increasing use of inverters, there are many faults that occur during their operation. These faults can be named partial shading, MPPT failure, battery or battery pack failures, semiconductor and gate drive failures, line or connection failures and inappropriate choice of converters. In this study, an innovation in MC-PWM modulation is proposed to reduce the low voltage faults due to battery failure or partial shading of PV panels. These situations caused aperiodic DC sources in ACMLI. A Matlab/Simulink simulation is performed for achieves the results of the proposed method. [13-15]

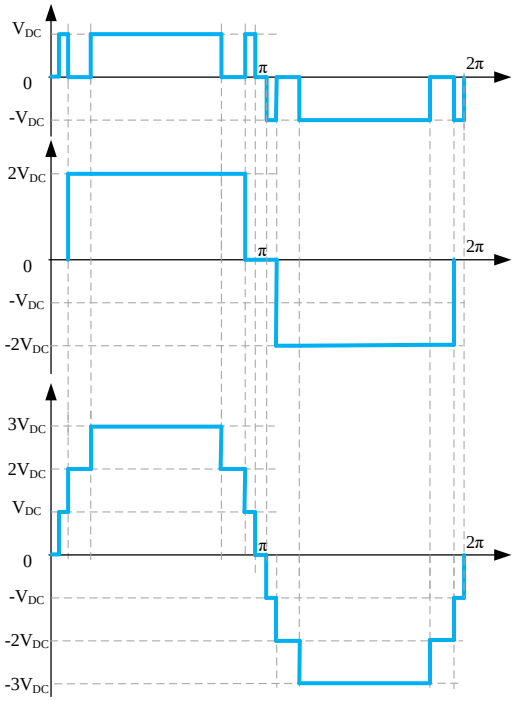

Figure 2. Seven Level ACMLI output voltage levels

Materials and Methods

Seven Level ACMLI

A seven level ACMLI has two H-Bridge cell in the structure. These combination of H-Bridges are binary structure and sources of inverter is VDC and 2VDC. ACMLI block diagram is shown in Figure 3. A LC filter is added to the output of inverter that values are 6 mH and 5 µF. Test and results are obtained with a RL load which values are 10 Ω and 50 mH. The switches block and MC-PWM block contents are depicted in Figure 4. Two H-Bridge cells have V1 and V2 sources which ratios are increments power of two. One sinusoidal signal and six triangle signal for a seven level ACMLI is shown in MC-PWM blocks.

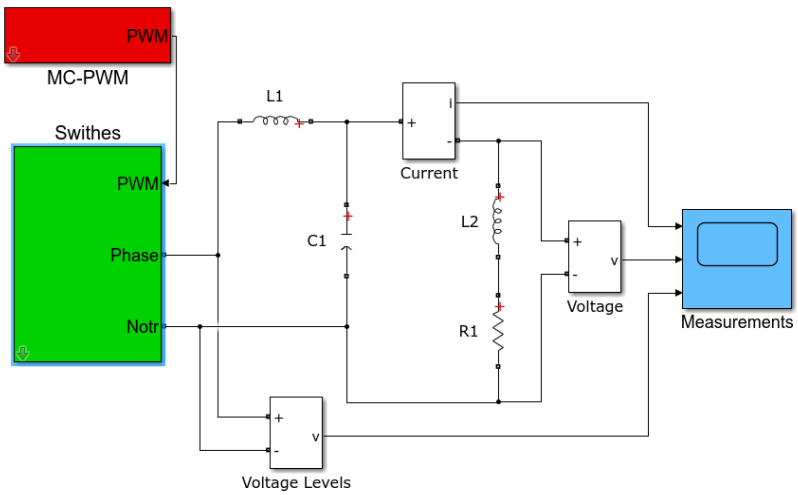

Figure 3. Seven Level ACMLI Simulink block diagram

Figure 5 shows out how generating the PWM signals for switches in H-Bridge. One sinusoidal signal is compared six triangular signals which are level shifted. These six triangular signal has same value in normal operation, and the modulation index (mi) can be defined in (3). N is the level number of the MLI, Vm and Vc are the amplitude of modulation signal and carrier signal, respectively [7, 10].

$$m_i = 2V_m /(N-1)\times V_c \tag{3}$$

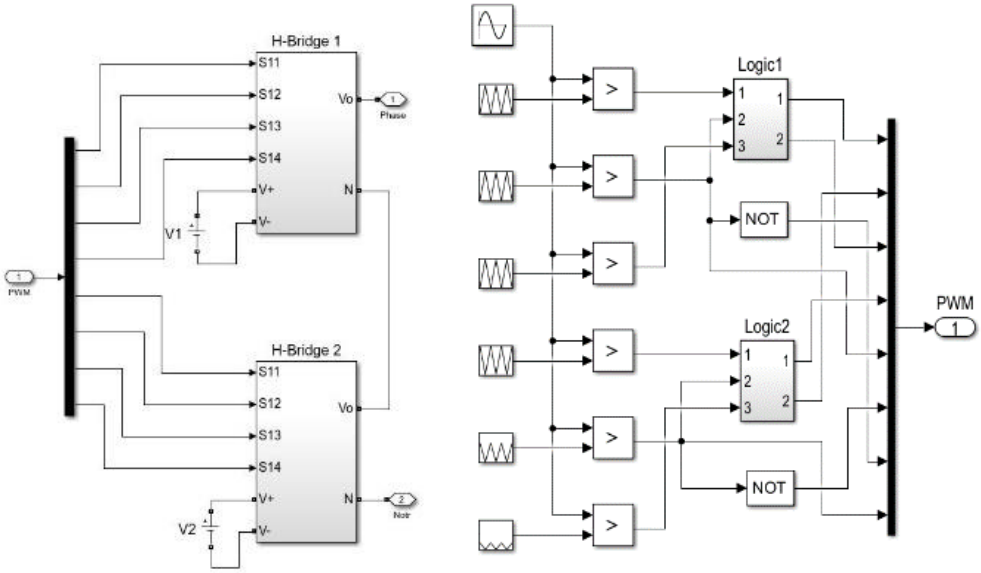

Figure 4. H-Bridge cells and MC-PWM modulation blocks

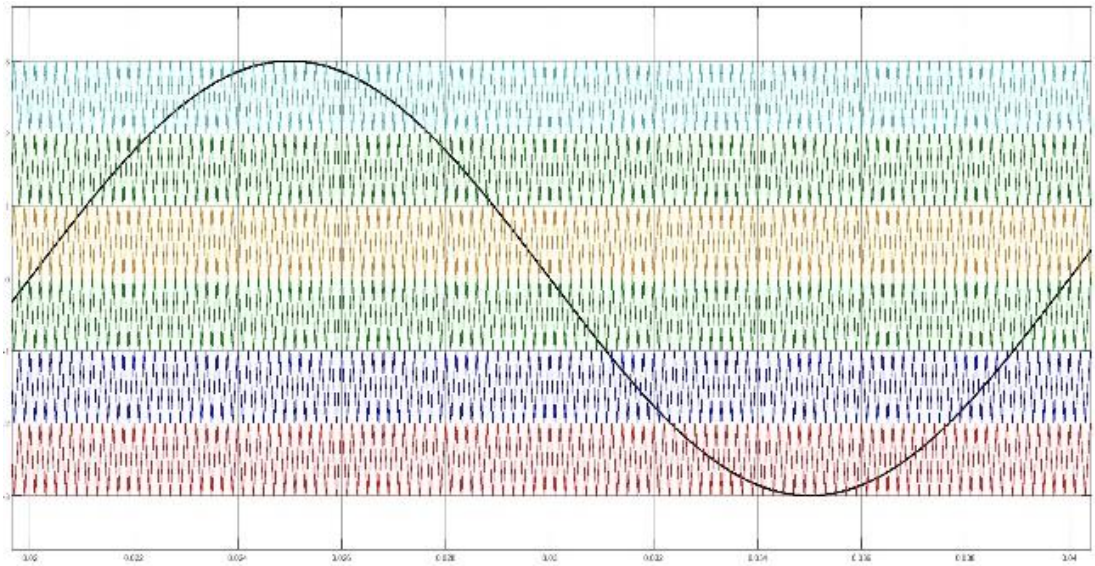

Figure 5. Generating switching signals in POD-PWM

Calculating the angle of the switching signals is operating as seen in Figure 6. The switching angles are θ1, θ2, …., θ8 and these points show the maximum value of the output voltage for level. Also, if we calculate the only θ1, θ2, other angles are detected by the quarter wave symmetry. π/2 is the maximum value of the first quarter. θ3 and θ4 can calculate by adding π/2 to θ1, θ2. The sinusoidal waves formula is shown in Equation

4. A is the amplitude (sum of the DC sources) and θ is the angle of the sinusoidal signal. Phase, frequency and time data is in θ. Actually, it is not needed to calculation of the switching angle in MC-PWM.

$$V_{\sin} = A \times \sin\theta \qquad \theta = 2\pi \times f \times t \tag{4}$$

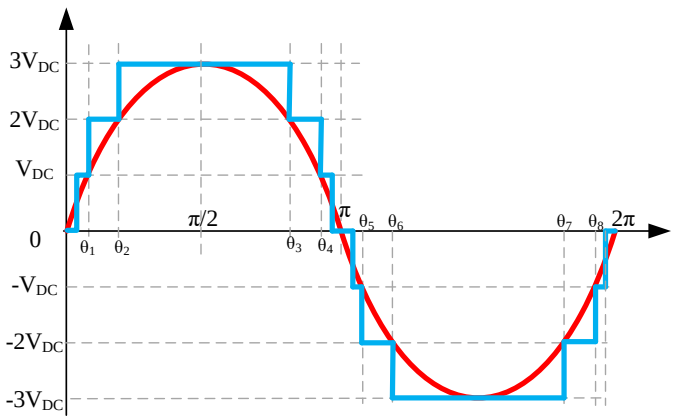

Figure 6. Calculating angle of the switching signals

It can be seen in Figure 7 that the generated switching signals in MC-PWM. For a seven level ACMLI, there is six triangular signals. These signals are organized in vertically between 0V/+3V and 0V/-3V. Final PWM point of the levels can be calculate with using Equation 5. with these calculations the triangular waves levels are calculated. Here, Vcn is the amplitude of the triangular signal for level of the Dc source, An is the amplitude of the DC source which is calculating for and A is the total voltage of the DC sources. The n is the number of the triangular wave. If Equation 5 is used for ACMLI which has periodic DC sources (V1=VDC, V2=2VDC), the triangular waves can be calculate Vc1=1V, Vc2=2V, Vc3=3V. Output Voltage THD is shown in Figure 8 with these triangular wave amplitudes, and the value of THD is 0.34%. The value of the DC sources (V1 and V2) are 150 V and 300 V respectively. The levels can be seen from the third waves in Figure 8.

$$V_{cn} = 3 \times \frac{A_n}{A} \tag{5}$$

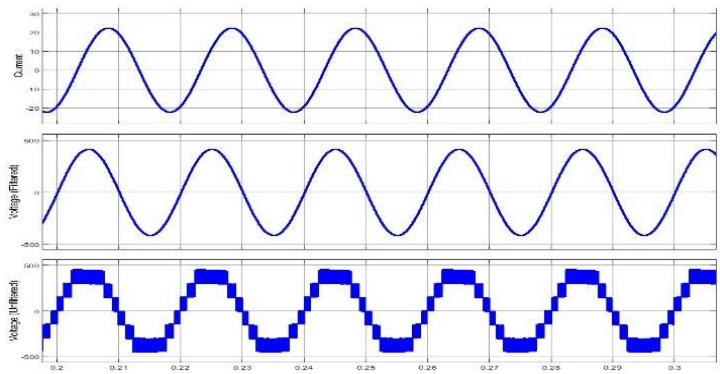

Figure 7. Generated PWM signals for levels

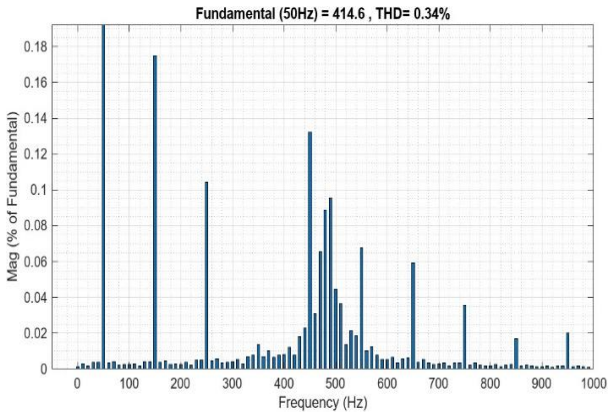

Figure 8. Output wave forms of the ACMLI and THD of voltage for periodic DC sources (150V-300V)

Seven Level ACMLI with Aperiodic DC Sources

Lots of faults can be occurred in a MLI operation. This study is the focused about battery or PV faults. Batteries can be connected series or parallel way in a battery pack. Output voltage can be decreased by battery faults in this pack. Another faults in MLI is caused by breakdown of PV panels or partial shadow. These faults constitute an under voltage fault. The DC sources are increased periodically in normal operation as seen previously simulation. If one of the sources decreased to the 50 V with same MC-PWM, output voltage waves and THD of voltage can be seen in Figure 9. THD of voltage is critically increased to the 19,79%. And the shape of the voltage wave is far from the sinusoidal. Output levels of ACMLI are still seven and it can be seen from the third waves in Figure 9.

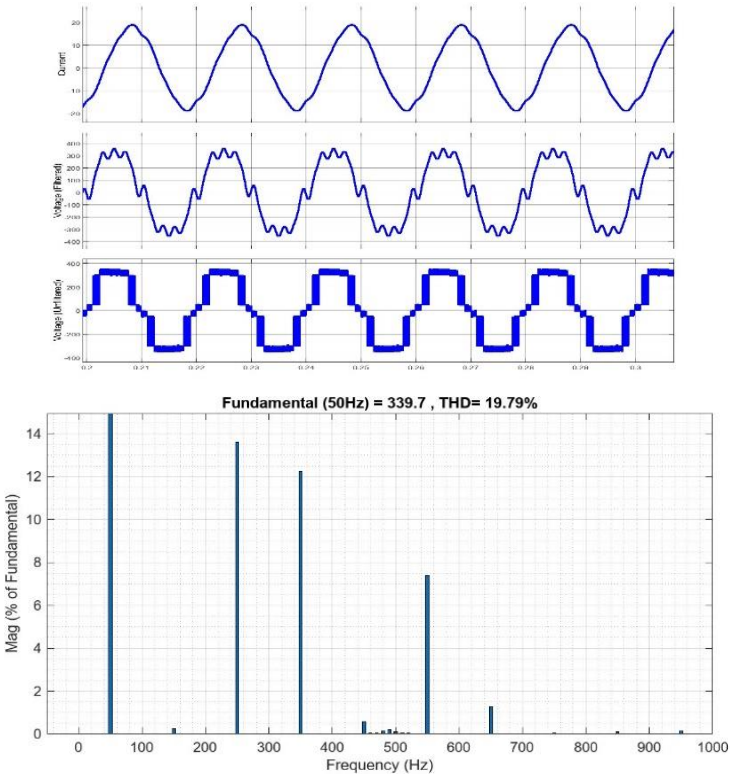

Figure. 9. Output wave forms of the ACMLI and THD of voltage for Aperiodic DC sources (50V-300V)

Findings and Discussion

Proposed MC-PWM and Simulation Results

This study is proposed a different MC-PWM structure for reducing the THD value of voltage. Proposed MC-PWM method is not changing any configuration in ACMLI. Only takes voltage value information from the DC sources. When a DC sources decrease, the switching angles θ1 or θ2 must be modified. This modification is generating new triangular waves in MC-PWM by using the Equation 5. These triangular waves have different amplitude. The block is used for generating amplitude value of new triangular waves which is depicted in Figure 10.

For example, if the value of the DC sources (V1 and V2) are selected as 50 V and 300 V, the new triangular waves the can be calculated as Vc1=0,375V, Vc2=2V, Vc3=3V. These new waves can be seen in Figure 11. First triangular wave between 0V-0,375V, second triangular wave is between 0,375V-2V and third triangular wave is between 2V-3V. The values of triangular waves are used with minus for negative alternate. The Output waves and THD values of voltage in simulation of these example are shown in Figure 12. The shape of voltage is better than normal MC-PWM method as can be seen second waves in Fig 12. Also Output levels of ACMLI are still seven and it can be seen from the third waves in Figure 12. The new THD value of voltage is 5,71%.

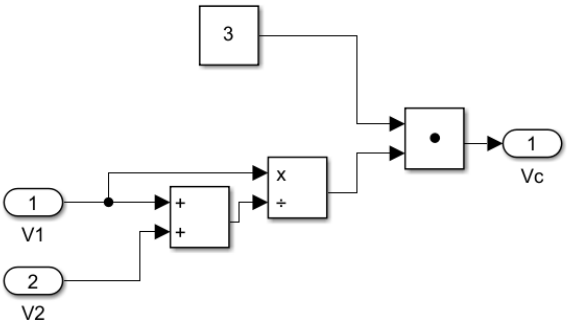

Figure 10. Generating switching signals in proposed MC-PWM

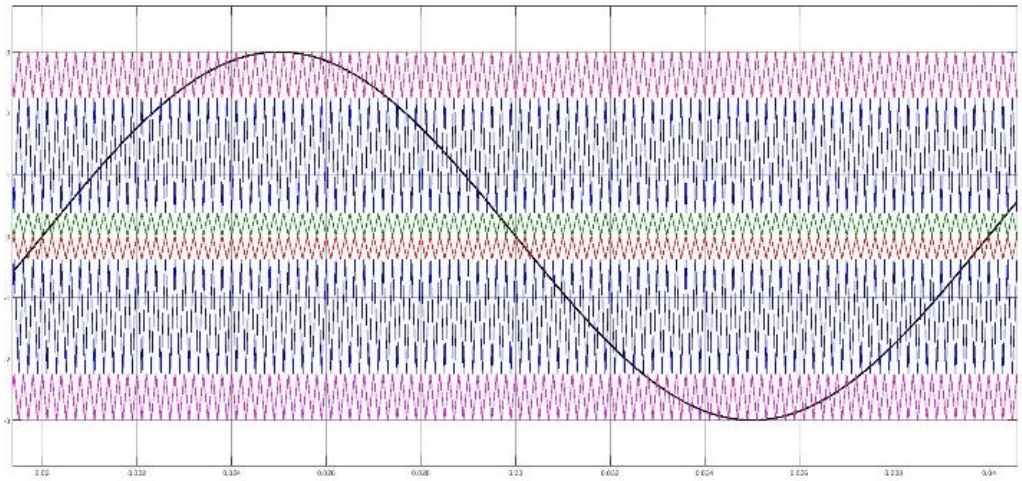

Figure 11. Generating switching signals in proposed MC-PWM

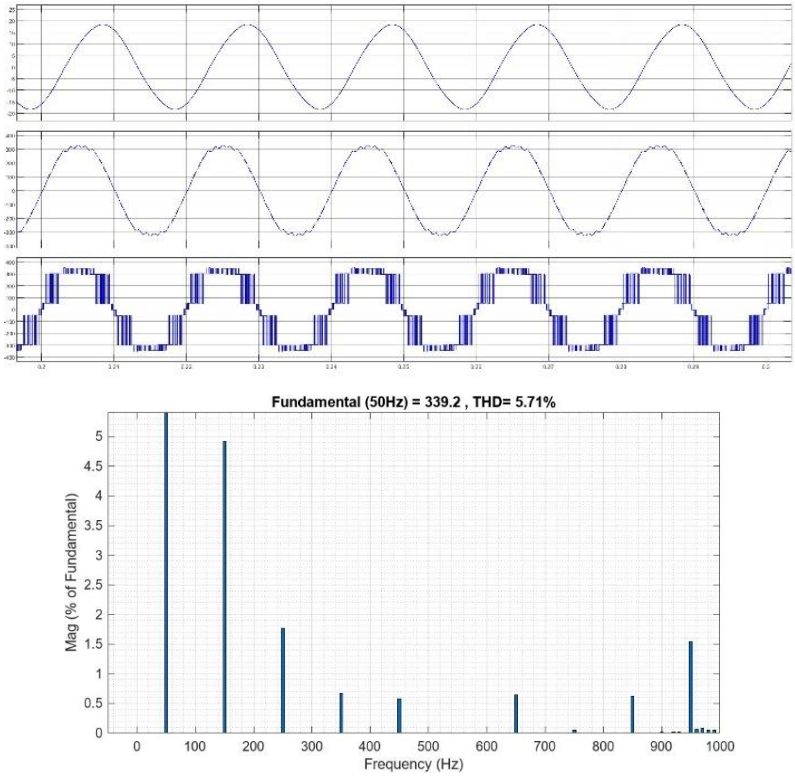

Figure 12. Output wave forms of the ACMLI and THD of voltage for Aperiodic DC sources (50V-300V)

Another example is tested for the proposed MC-PWM. In these example, the DC sources (V1 and V2) are selected as 100V and 300V. The new triangular waves the can be calculated as Vc1=0,75V, Vc2=2V, Vc3=3V. First triangular wave between 0V-0,75V, second triangular wave is between 0,75V-2V and third triangular wave is between 2V-3V. The Output waves and THD values of voltage in simulation of second example are shown in Figure 13. THD value of voltage is 1,74%.

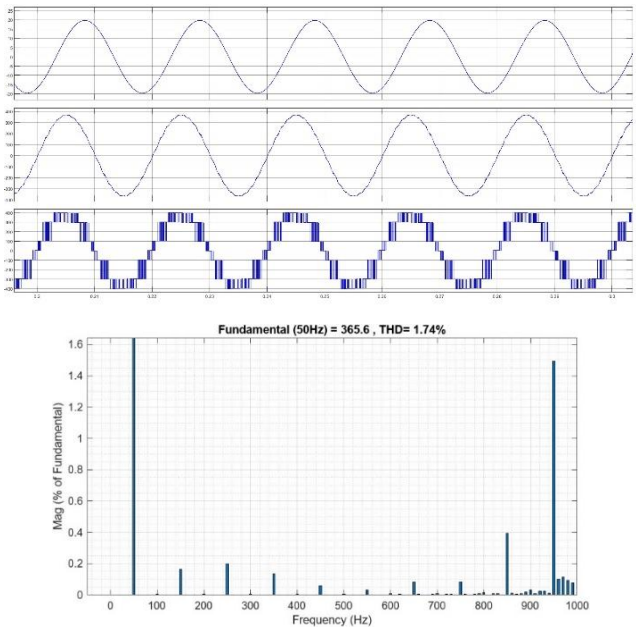

Figure 13. Output wave forms of the ACMLI and THD of voltage for Aperiodic DC sources (100V-300V)

Conclusion and Recommendations

Proposed MC-PWM is controlled with different DC sources in simulation. Firstly, some different voltage values are chosen and MC-PWM signal values are calculated. Table 1 shows the values range of triangular waves for MC-PWM modulation in seven level AC-MLI.

Table 1. The MC-PWM signal values at different DC sources

	V1	V2	V_{c1}	V_{c2}	V_{c3}
1	50	400	0-0,33	0,33-2,67	2,67-3,00
2	50	300	0-0,43	0,43-2,57	2,57-3,00
3	50	200	0-0,60	0,60-2,40	2,40-3,00
4	75	400	0-0,47	0,47-2,53	2,53-3,00
5	75	300	0-0,60	0,60-2,40	2,40-3,00
6	75	200	0-0,82	0,82-2,18	2,18-3,00
7	100	400	0-0,60	0,60-2,40	2,40-3,00
8	100	300	0-0,75	0,75-2,25	2,25-3,00
9	150	200	0-1,29	1,29-1,71	1,71-3,00
10	150	100	0-1,80	1,80-2,20	2,20-3,00

The simulations of the seven level AC-MLI with different DC sources are occurred with Matlab/Simulink. Voltage THD values are calculated for standard MC-PWM and proposed MC-PWM. It can be seen from Table 2 that proposed MC-PWM method achieves less THD. At the other hand, if the value of V2 is get down from the value of V1, the THD value of the voltage could not be reduced as desired.

Table 2. The Voltage THD values of different values of DC sources

	V1	V2	THD (MC-PWM)	THD (Proposed MC-PWM)
1	50	400	22,89%	1,44%
2	50	300	19,79%	1,15%
3	50	200	14,07%	0,85%
4	75	400	18,30%	1,06%
5	75	300	14,07%	0,85%
6	75	200	6,55%	1,10%
7	100	400	14,07%	0,85%
8	100	300	8,93%	1,74%
9	150	200	10,67%	1,81%
10	150	100	31,46%	22,18%

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CONTROL and COMPARISON of A TIME-DELAYED SYSTEM USING A PD, 2DOFPD, and FOPD CONTROLLER

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ABSTRACT

Time-delayed systems are prevalent in industrial processes and are commonly encountered in chemical and fluid systems, manufacturing plants, communication networks, and defense industry operations. This study employs PD, fractional order PD (FOPD), and two degrees of freedom PD (2DOFPD) controllers to manage an example of a time-delayed system. In addition to analyzing the responses to unit step input, the system's resilience to introduced disturbances was also tested and the results were examined. In addition, the controllers' efficacy against errors was evaluated using performance indices such as Integral Square Error (ISE), Integral of Absolute Value of Error (IAE), Integral of Time-weighted Absolute Error (ITAE), and Integral of Time-weighted Square Error (ITSE). Additionally, these controllers were recalibrated through precise adjustments, and a subsequent performance comparison was conducted. The simulation of the system was fully conducted in the Matlab/Simulink environment, and the results are presented for further discussion.

Keywords: time delay system, fractional order PD, two degrees of freedom PD, integral of time absolute error, control systems.

Introduction

Time-delay systems are commonly encountered in industrial processes, such as fluid-gas flow, and in communication systems where time delays occur. The natural time delay in the system causes problems in process control. To overcome this issue, controllers must be adjusted to tolerate this time delay. This situation leads to different controllers achieving different outcomes. Determining which controller to use in a given situation, or which type will be sufficient, presents a significant challenge (Åström & Hägglund, 2001; Dorf & Bishop, 2020). Therefore, alongside the most fundamental industrial controller, the PID controller, others such as 2DOFPID, KDPID, and their versions with added filters can be used for comparison purposes (Dong et al., 2024; Xia et al., 2023; Sundaravadivu, 2015). Additionally, controllers derived from artificial intelligence, such as fuzzy logic controllers (Manuel et al., 2023) and genetic algorithms (Gürler et al., 2023), can also be used (Chen et al., 2023). Moreover, hybrid-structured controllers such as fuzzy-tuned PID are also available (Liu et al., 2023).

Determination of controller parameters and evaluation of their performance for comparison require certain parameters. This helps to identify the aspects in which one controller performs better than others. For this purpose, error performance indices such as integral square error (ISE), integral of the absolute value of error (IAE), integral of time-weighted absolute error (ITAE), and integral of time-weighted square error (ITSE) values are commonly used (Mengi et al., 2022). In addition, parameters such as steady-state error value, maximum overshoot, and settling time are also considered in the design (Ayas & Sahin, 2021).

In this study, a time-delayed sample system was controlled using PD, 2DOFPD, and FOPD controllers, and efforts were made to highlight the differences between these controllers. The results are presented both graphically and numerically in tables.

Materials and Methods

This study compared the performance of three different types of controllers to identify their distinct characteristics. The controllers examined were PD, 2DOFPD, and FOPD types. These were tested in a simulated industrial process that mirrored the typical time delays found in real-world industrial environments.

The experimental setup was designed to independently evaluate the performance of each controller. Key aspects such as response time, stability, and adaptability to time delays of the controllers were scrutinized. For the evaluation process, error performance indices such as ISE, IAE, ITAE, and ITSE were used. Additional parameters, including steady-state error, maximum overshoot, and settling time, were also considered.

This approach ensures a comprehensive analysis of each controller, allowing for an in-depth understanding of their operational capabilities and limitations within a time-delayed process environment.

Time-Delayed Systems

Time-delayed systems are complex dynamic systems that are commonly encountered in industrial and engineering applications. These systems are usually expressed mathematically, as shown in Equation 1. The key characteristic of this equation is that it reflects how the system's past states affect its current state, which is identified as time delay. This time delay may result from various factors, such as the speed of the control cycle or the communication network in the system.

Analyzing these systems is more complex than that of traditional control systems and can significantly impact the stability and performance of the systems. The dynamics of time-delayed systems are often observed in fluid and gas flows, communication networks, and even economic models. Accurate modeling and analysis of these systems are crucial for the development of effective control strategies.

In this study, the mathematical modeling of time-delayed systems is based on the approach proposed by Luyben (Luyben, 2003). Luyben's model, commonly used in industrial process control, reflects the fundamental characteristics and control challenges of these systems. This modeling serves as a cornerstone for testing and evaluating the performance of the controllers used in this study.

$$G(s) = \frac{K(-\tau_a s + 1)e^{-\theta s}}{s(\tau s + 1)} \tag{1}$$

PID Controller

PID controllers are widely favored because of their simplicity, affordability, quick response, and user-friendly nature (Güven & Duman, 2017). Commonly, their parameters K_P, K_I, and K_D are tuned using the Ziegler–Nichols technique. Further adjustments are made through various methods such as optimization algorithms to meet specific requirements. The formula for the PID controller is shown in Equation (2), and its design is depicted in Figure 1.

$$c(s) = \frac{U(s)}{E(s)} = K_P + \frac{K_i}{s} + K_d s \tag{2}$$

K_P, K_I, and K_D are PID controller gains. Here, $U(s)$ is the control signal and $E(s)$ is the error signal (Mengi, 2020).

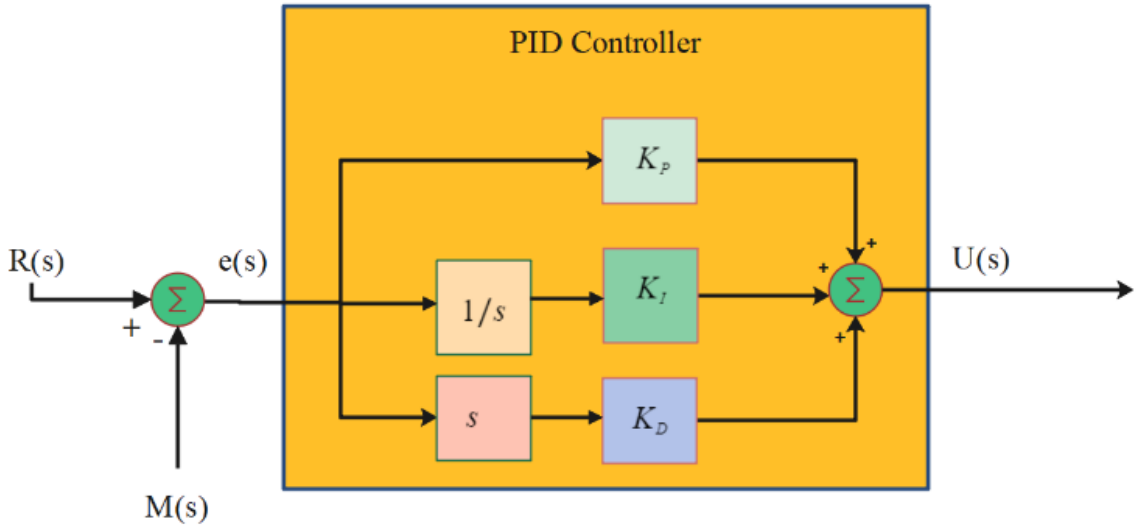


Figure 1. ***PID controller***

2DOFPID Controller

2DOFPID controllers are more sophisticated and precise variants of PID controllers. They are engineered to uphold superior performance in demanding and varying system conditions. Uniquely, they afford two degrees of freedom for both error and its derivative (Güven, 2023). This added attribute allows the 2DOFPID controller to deliver enhanced control and adaptability compared with a conventional PID controller in numerous situations. Their mathematical representations are shown in Equations (3) and (4).

$$u = K_P[(br - y) + \frac{1}{T_i s}(r - y) + \frac{T_D s}{\frac{T_d}{N}s + 1}(cr - y)] \tag{3}$$

$$u = K_P(br - y) + \frac{K_i}{s}(r - y) + \frac{K_d s}{T_f s + 1}(cr - y) \tag{4}$$

Here c is set point weighting (derivative), b is set point weighting (proportional), T_f is derivative filter time (s), T_i is integrator time (s), T_d is derivative time (s) and N is filter coefficient (Thakallapelli et al., 2016). This structure is shown in Figure 2.

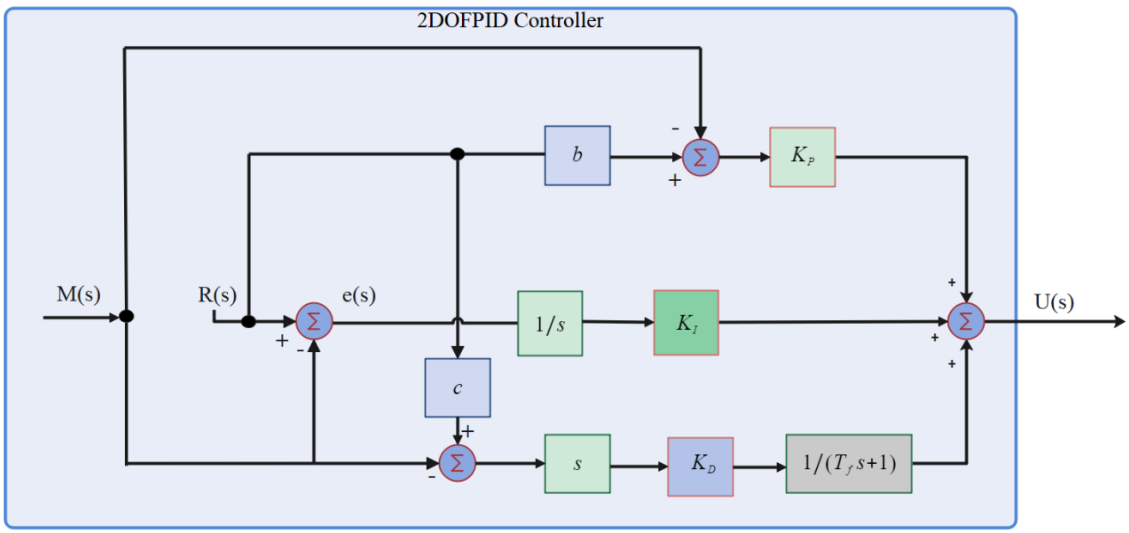


Figure 2. ***2DOFPID controller***

Fractional-Order PID Controller

A fractional-order PID (FOPID) controller is an enhanced form of the conventional PID controller, characterized by a fractional order of the integral operator (λ) and a fractional order of the derivative operator (μ) (Ahmed et al., 2023). The transfer function for the FOPID controller is provided as follows.

$$G_{CONTROLLER} = K_P + \frac{K_i}{s^{\lambda}} + K_D s^{\mu} \tag{5}$$

The controller is designed with five adjustable parameters: K_P, K_i, λ, K_D, μ. These extra parameters offer greater control and enhanced capability to counter disturbances, leading to improved system dynamics over traditional PID controllers. Figure 3 illustrates the FOPID controller's block diagram.

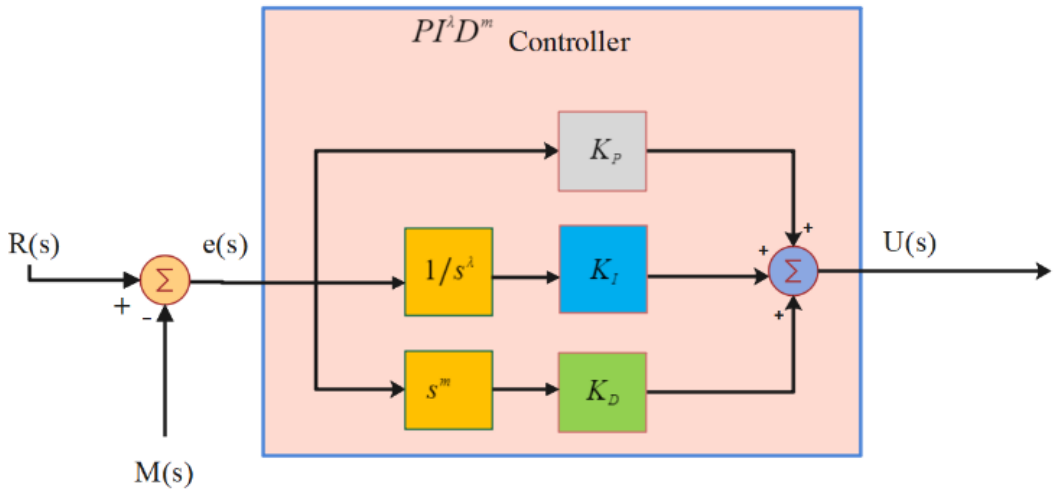


Figure 3. $PI^{l}D^{m}$ controller

Performance Indices

To evaluate the effectiveness of PID controllers, various performance indices were employed. Notably, IAE, ITAE, ISE, and ITSE are among the most commonly used. These indicators are assessed on the basis of the evolution and cumulative value of the error over a given period. In this study, the ITAE index was selected for performance measurement. The formulas for these indices are outlined in Equations (6) to (9) (Mengi, 2022).

$$\mathrm{ISE} = \int_0^{\infty} e^2(t)\,dt \tag{6}$$

$$\mathrm{IAE} = \int_0^{\infty} |e(t)|\,dt \tag{7}$$

$$\mathrm{ITSE} = \int_0^{\infty} te^2(t)\,dt \tag{8}$$

$$\mathrm{ITAE} = \int_0^{\infty} t|e(t)|\,dt \tag{9}$$

To calculate the ITAE value, a specialized computational module was developed using the Matlab/Simulink platform.

Findings and Discussion

The simulated system is illustrated in Figure 4. The transfer function of the time-delayed sample system is presented in Equation 10 as follows:

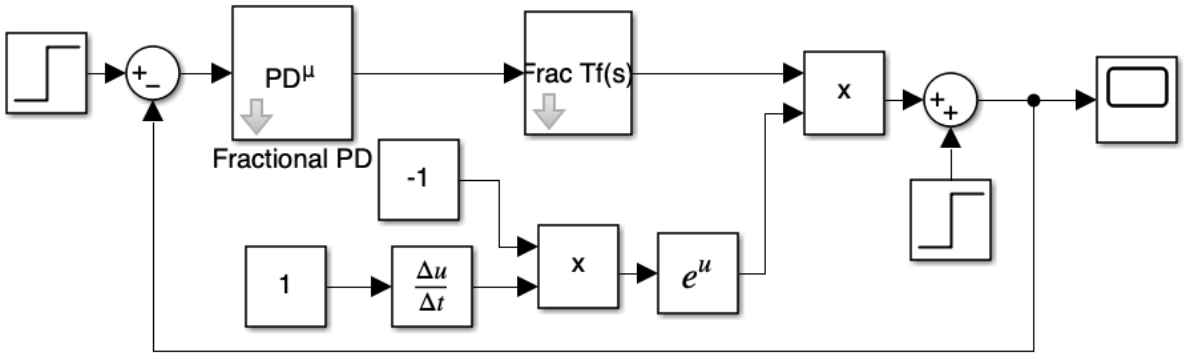


Figure 4. Simulated system

$$G(s) = \frac{1}{s^{1.9} + s} e^{-s} \tag{10}$$

For this system, PD-type controllers have been recommended in the literature (Özyetkin et al., 2018). The performance of the 2DOFPD and KDPD controllers was compared with that of standard PD-type controllers. Subsequently, efforts have been made to obtain more effective results using fine-tuning features in the Matlab/Simulink environment.

Study 1:

Figure 5 displays the outputs obtained using the controller parameters referenced in the literature. In this case, a disturbance of 0.2 units was introduced to the system at t=15s to also test the effectiveness of the controllers. A unit step function served as the reference input and was applied at t=1s.

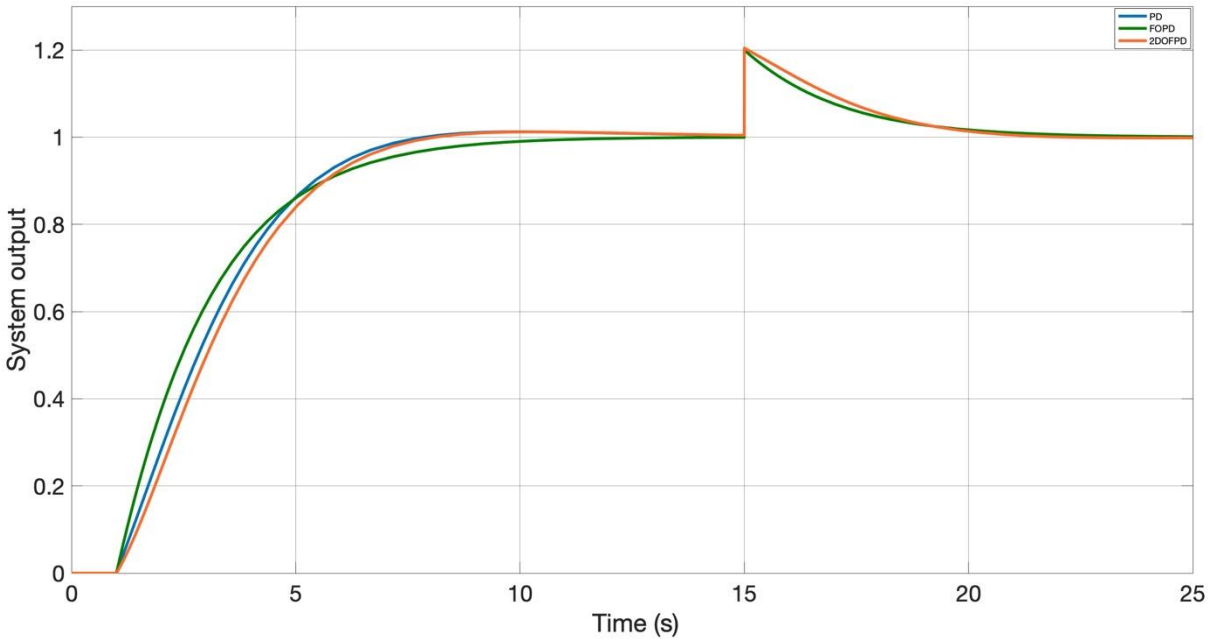
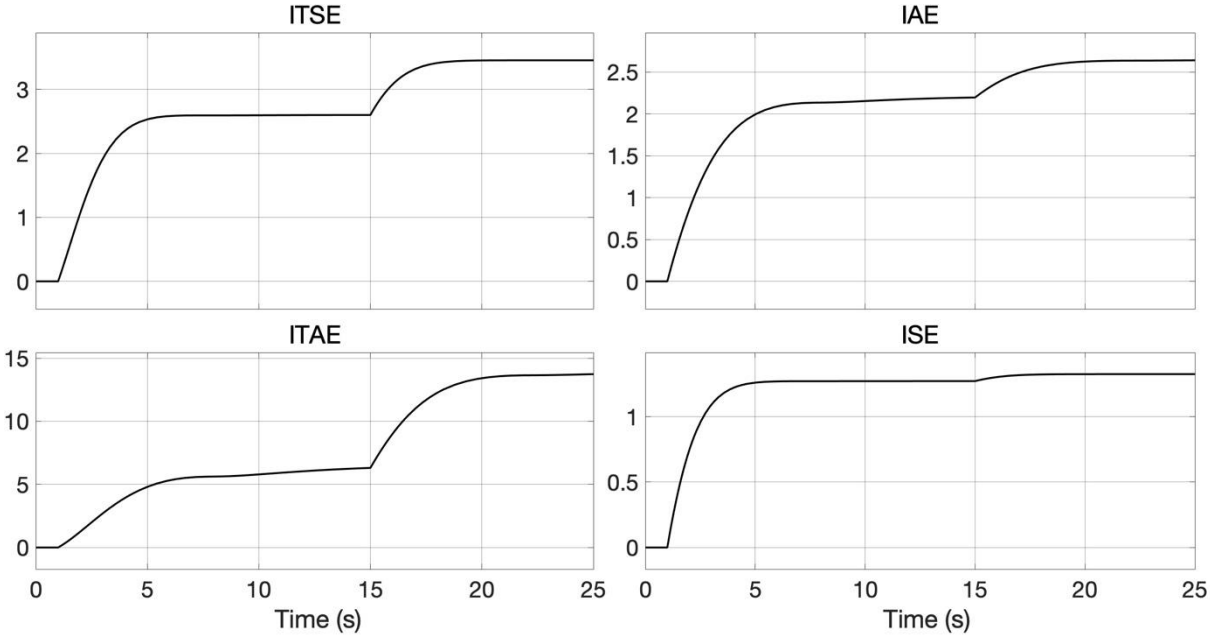
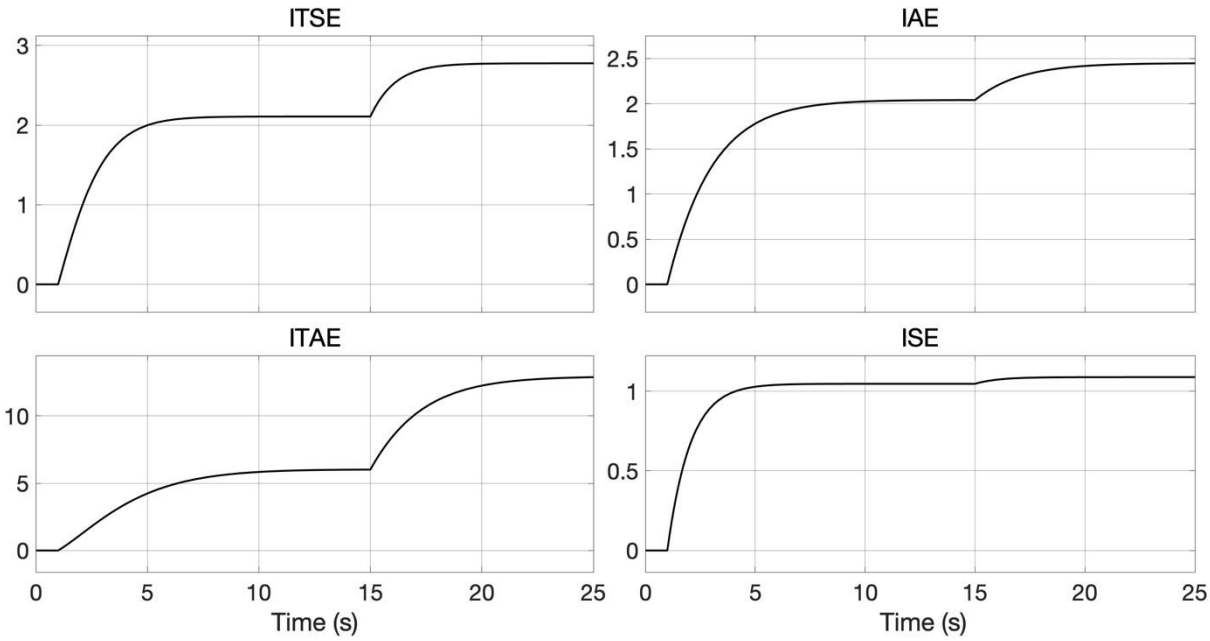


Figure 5. Variation of system output

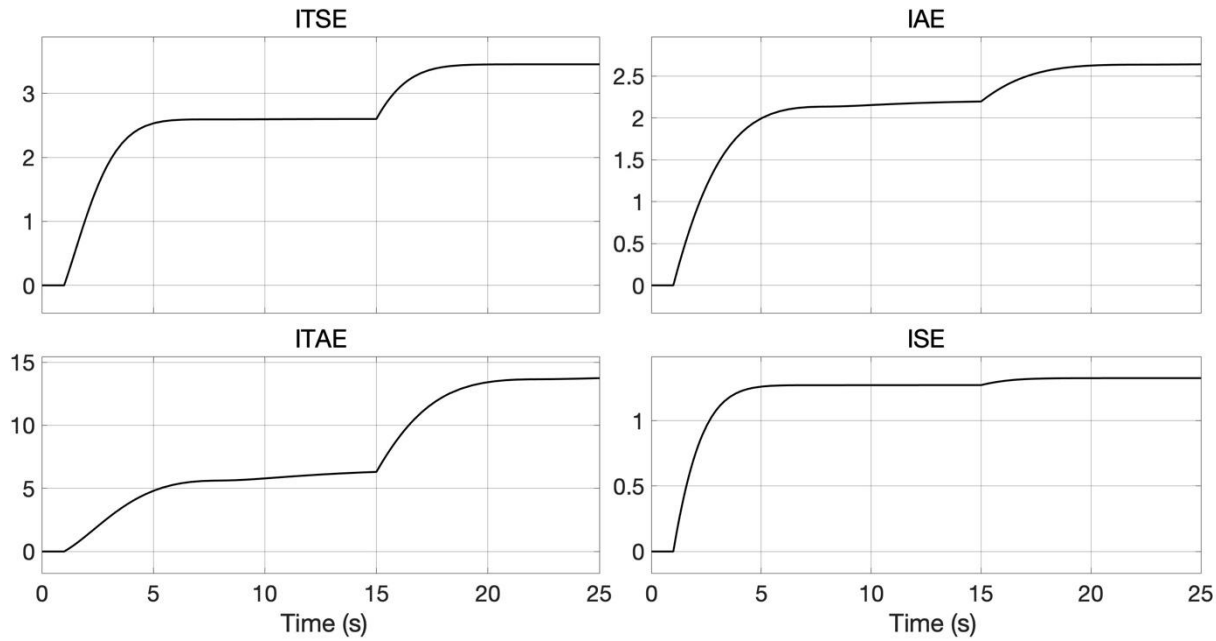
Figure 6 (a) shows the variation of error indices for the PD controller, Figure 6 (b) for the KDPD controller, and Figure 6 (c) for the 2DOFPD controller.



(a) PD



(b) KDPD



(c) 2DOFPD

Figure 6. Variation of error Indices for the PD controller

Table 1 presents a comprehensive view of the controller parameters and the error index values.

Table 1. Controller parameters and performance index values

Controller	K_P	K_I	K_D	λ	μ	b	c	ISE	IAE	ITSE	ITAE
PD	0.4906	-	0.4532	-	-	-	-	1.32	2.63	3.45	13.73
2DOFPD	0.4906	-	0.4532	-	-	1	0.6	1.32	2.63	3.45	13.73
KDPD	0.4906	-	0.4532	-	0.9	-	-	1.08	2.44	2.77	12.89

If observed closely, it can be seen that except for KDPD, the other two controllers yielded almost identical results. In terms of the same parameters, the KDPD controller showed the best performance. As indicated in Table 2, when comparing these three controllers, it is evident that the error values are significantly low. However, the settling times for KDPD are lengthy, at 14 s. In contrast, the others have settled at the unit step value with a very small error margin.

Table 2. Controller response

Controller	M_P	t_s (s)	e_{ss}
PD	0.1	-	0.042
2DOFPD	0.1	-	0.045
KDPD	0	14	0

Study 2:

Figure 7 shows the outputs obtained after the controllers in Matlab/Simulink are fine-tuned. As in the previous study, a disturbance of 0.2 units is added to the system at t=15s. A unit step is used as the reference and is applied at t=1s.

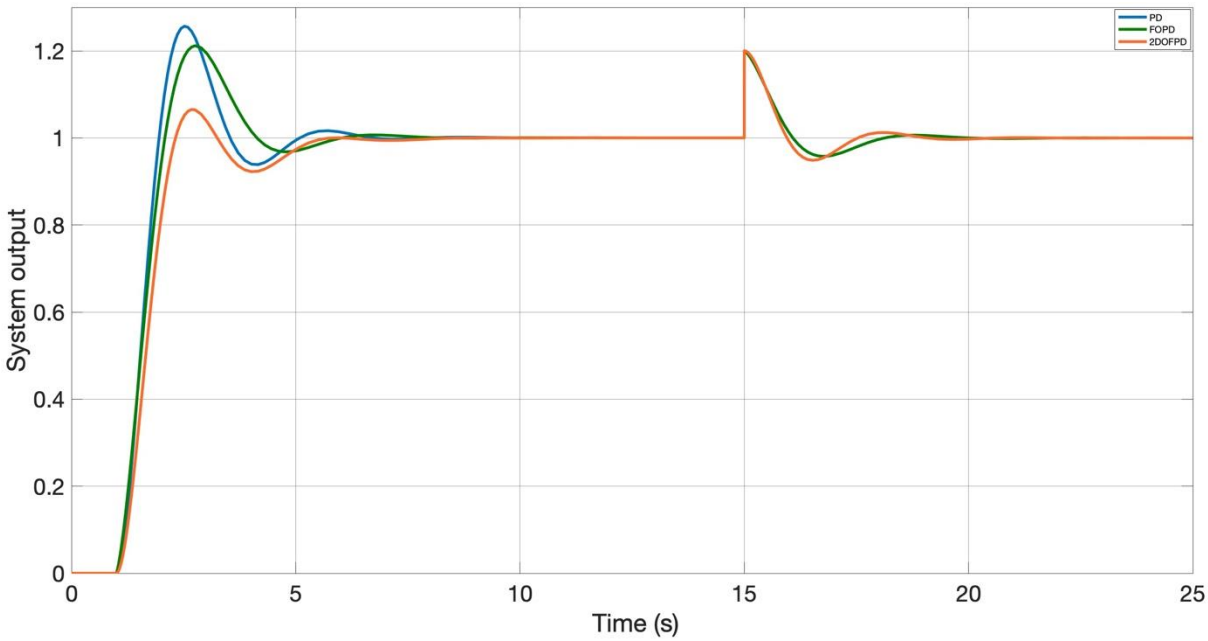
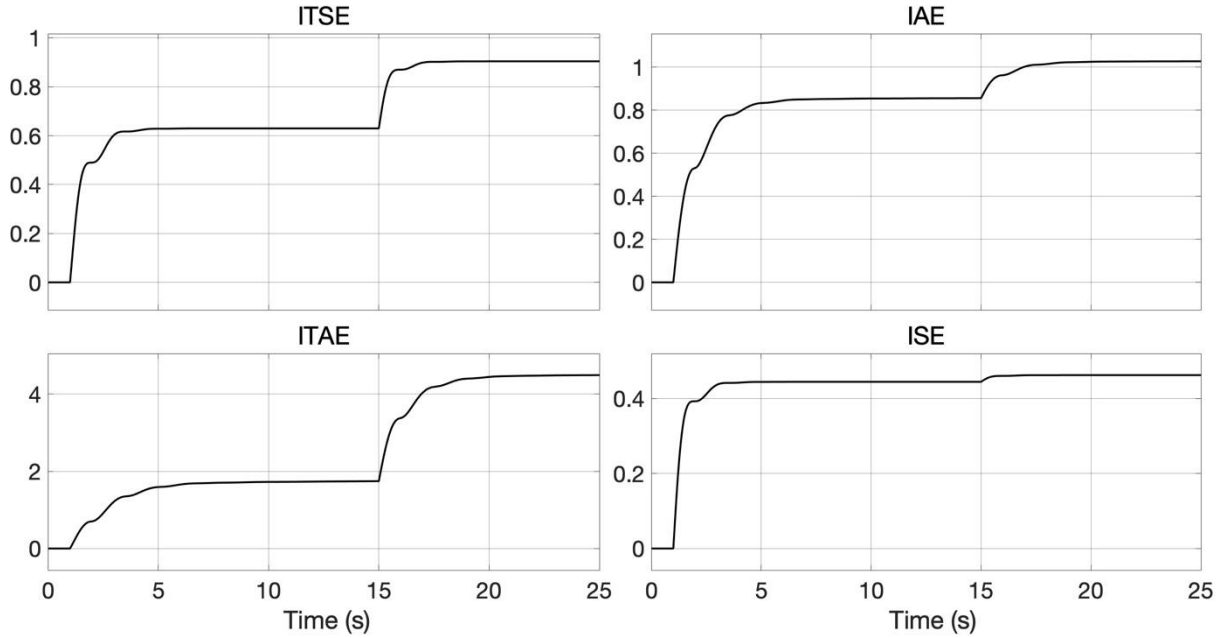
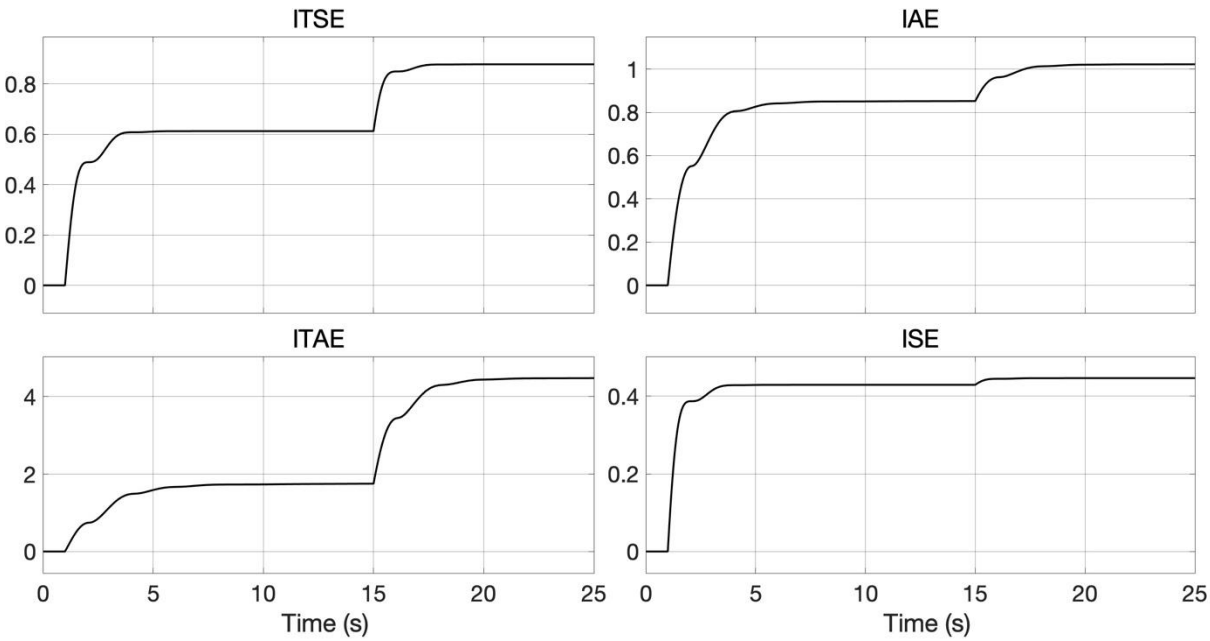


Figure 7. Change in demand output using fine-tuned controllers

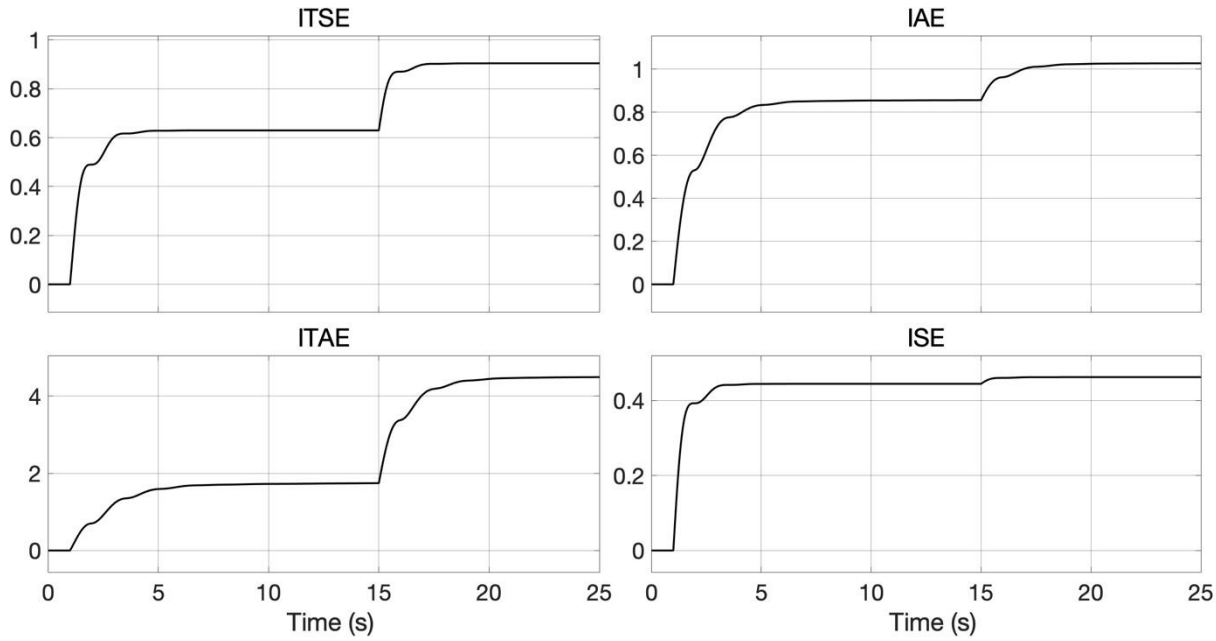
In Figure 8a, the changes in error indices of the PD controller, in Figure 8b, the KDPD controller, and in Figure 8c, the 2DOFPD controller are shown.



(a) PD



(b) KDPD



(c) 2DOFPD

Figure 8. Variation of error indices for the PD controller

Table 3 presents a comprehensive view of the controller parameters and their corresponding error index values.

Table 3. Controller parameters and performance index values

Controller	K_P	K_I	K_D	λ	μ	b	c	ISE	IAE	ITSE	ITAE
PD	3.133	-	0.415	-	-	-	-	0.46	1.027	0.9	4.49
2DOFPD	3.133	-	0.415	-	-	1	0.006	0.46	1.027	0.9	4.49
KDPD	3.133	-	0.415	-	0.85	-	-	0.446	1.022	0.877	4.478

In the analysis conducted after fine-tuning, it was observed that all values closely approached each other. This situation has made interpreting the error indices challenging. Table 4 shows that when these three controllers are compared, the error values are zero. However, the settling times for all controllers are 8 s. However, the maximum overshoot value is the lowest for the 2DOFPD, at 0.065. After fine-tuning, the controllers have zeroed their errors.

Table 4. Controller response

Controller	M_P	t_s (s)	e_{ss}
PD	0.25	8	0
2DOFPD	0.065	8	0
KDPD	0.212	8	0

Conclusion and Recommendations

In the quest to control a system characterized by time delays, this study used three distinct types of controllers and conducted a thorough comparative analysis of their performances (Özyetkin et al., 2018). Initially, parameters previously identified for a system with a KDPD controller in the literature were employed, yielding initial results. This was followed by trials using the same parameters but with a classical PID controller and a 2DOFPD controller, leading to a comparative assessment of the outcomes. In this phase, the KDPD controller emerged as the most effective, a conclusion that became evident upon a detailed examination of both error indices and errors of the controllers themselves.

Further explorations, involving the use of the fine-tuning function within Matlab/Simulink, enable automatic adjustments to the system. The controller parameters derived from this process are presented in Table 3. When the system was re-evaluated with these adjusted parameters, it was observed that, although there were no significant discrepancies in error indices among the three controllers, a more granular analysis of controller errors revealed that the 2DOFPD controller demonstrated a superior performance, particularly in terms of minimizing maximum overshoot. A comparison between Studies 1 and 2 revealed a notable reduction in error values and a decline in error index values. Moreover, there was a discernible decrease in the settling times. Significantly, the settling time, which was indeterminable in Study 1, was successfully calculated in Study 2.

The decision regarding the optimal type of controller for regulating systems is a critical aspect of control engineering. This study elucidates this point vividly. While the KDPD controller was found to be most effective in Study 1, the 2DOFPD controller yielded the best results in Study 2. This finding underscores the premise that determining the most effective controller without practical testing is not feasible.

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PREDICTION OF THE ELECTRONIC TRANSITIONS OF BENZENE USING THE CHARACTER TABLE AND THE CONJUGACY CLASSES OF THE DIRECT PRODUCT OF PAIR OF DIHEDRAL GROUPS

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ABSTRACT

The electronic transitions of benzene have been studied using group theory concepts. The D_{6h} point group of benzene was determined, and its symmetry elements and operations were identified. The character table of the D_{6h} point group was constructed, and the symmetry of the relevant π-electron molecular orbitals of benzene was determined using the character table. The electronic spectrum of benzene was analyzed using group theory, and the allowed and forbidden electronic transitions were predicted based on symmetry arguments. The results of this study demonstrate the usefulness of group theory in predicting the electronic properties of molecules and provide insights into the electronic transitions of benzene.

Keywords: Electronic Transmission, Benzene, Molecules, Group Theory, Point Group Symmetry, Dihedral Groups, Character Table, Conjugacy Classes, Symmetry Operations

1. INTRODUCTION

The application of Group theory concepts to study of electronic transitions in molecules is becoming increasingly relevant and is crucial for understanding their optical properties; see [10] and [12]. Symmetry as a concept is more of mathematics subject and not physics or chemistry. However, the underlying mathematical theory for symmetry and group theory are of great importance in physics and chemistry because they can be used to solve quite plenty of physics and chemistry problems. For example it can be applied when it comes to analyzing the electronic spectrum of benzene and predict the energy levels of its π-electrons.

Benzene is a cyclic aromatic hydrocarbon with six carbon atoms and six hydrogen atoms. It has a planar structure with alternating single and double bonds between the carbon atoms. The molecular orbitals of benzene are formed by the linear combination of the atomic orbitals of the carbon atoms. The molecular orbitals can be classified into two types: bonding and antibonding. Bonding orbitals are lower in energy and more stable than antibonding orbitals. Antibonding orbitals are higher in energy and less stable than bonding orbitals. Benzene exists as a chemical compound with molecular formula as C_6H_6. The electronic transitions of benzene are the changes in the occupancy of the molecular orbitals due to the absorption or emission of photons. The electronic transitions of benzene can be predicted by using the character table and the conjugacy classes.

Full rigid molecules' symmetry properties are well known and so investigating them is a natural thing to do, though study in this research area is new in chemistry. [14] presented a number of papers on the determination of character tables of restricted f-NRG of some chemical molecules. For example, Computation of the r-NRG of the triple equivalent methyl rotation in pyramidal trimethylamine with inversion was done by [15]. The authors proved that the r-NRG of this molecule is a group has 648 elements, consists two subgroups of order 324 without inversion. We also have in [4] and [5] where computation of full non-rigid group of some other molecules were carried out. In the same vein, [1] computed full non-rigid group of tetra-ammine platinum (II), trimethylamine, tetraammine platinum (II), etc which are all examples of C2v and C4v point groups. Authors such as [2] and [7] proved that molecular structure tetra-amine platinum (II) is isomorphic to the Wreath Product of certain degree. [8] worked on hexamethylbenzene while [9] and [3] studied melamine.

2. MATERIALS AND METHODS

Dihedral groups, the groups of symmetries of a regular polygon, which consist of rotations and reflections according to Cameron (2013) are good examples of finite permutation groups and have series of applications

especially in natural sciences and engineering. There are two notable notations for dihedral groups associated with a polygon with n regular sides or degree namely D_n and D_{2n}. In this work, we shall stick to D_n which symbolizes the symmetry of a regular polygon with n sides (that is, the dihedral group of degree n).

Conventionally, we write $D_n = \langle r, f \mid r^n = f^2 = 1,\ fr = r^{n-1}f = r^{-1}f \rangle$ and we say that D_n is the group generated by the elements *r* and *f* subject to the conditions.

The direct product of a pair of dihedral groups is a mathematical concept that arises in group theory. Specifically, the dihedral group of order 2n, denoted by D_n, can be expressed as a direct product G × H of two nontrivial groups if and only if n = 2. In general, the direct product of two groups G and H is a new group that consists of all possible pairs of elements (g, h), where g is an element of G and h is an element of H, with the group operation defined componentwise. The direct product of two dihedral groups can be calculated using the rules for direct products of irreducible representations, which are necessary for working through transition moment integrals in chemistry.

In this paper, we employ group theory concepts to simplify the analysis of the electronic spectrum of benzene by predicting the allowed and forbidden electronic transitions, as well as the selection rules for these transitions. Then, on the bases of the structure of the group, a useful computational group theory, namely, "Groups, Algorithms and Programming" (GAP) is used to compute the contumacy classes and the character table. The use of this computational group theory package (GAP) is capable of revealing many properties of a group according to [11] and [13]. We calculate the order of the point group of benzene from the character table.

3. MAIN RESULT AND DISCUSSION

Benzene molecules belong to the D_{6h} point group since it has a principal axis of rotation of C_6, and contains two C_3 axes. However, the C_3 axis lies along the C_6 axis, and both run through the center of the ring perpendicular to the plane of the molecule. This axis is also a C_2 axis.

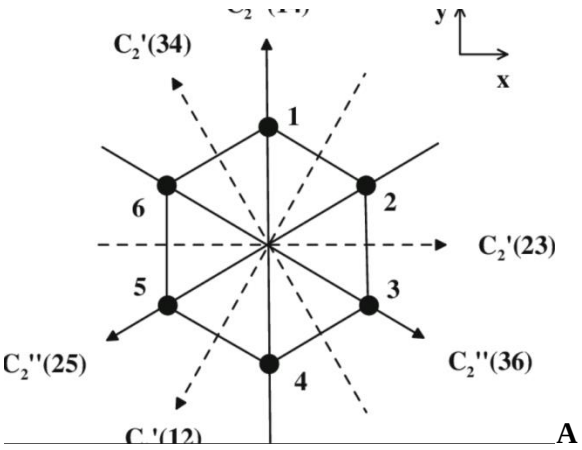
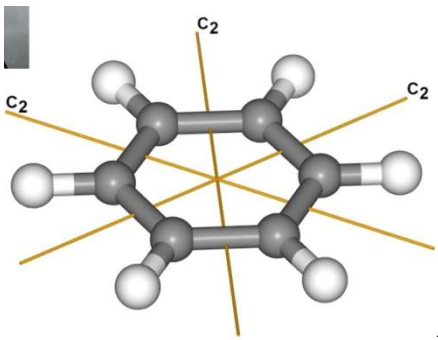


Figure 1: **Benzene Structure.**



B

Figure 2: **Benzene Geometry.**

Where A = Structure of Benzene

B = Geometry of Benzene

From figure 1 we have a C_6 principal axis, and six additional C_2 axes, but no other symmetry element. The C_6 axis stands perpendicular to the paper plane, and the six C_2 axes are in the paper plane. Therefore the symmetry of C_6H_6 has a hexagonal shape which is a dihedral group of degree 6. The C_6 axis goes through the centre of the atom of the C molecules, and the three C_2 axes go through the six H atoms. The C_6H_6 symmetry elements, namely C_6 and C_2 axes, are denoted by $C_3 := \langle(1,2,3,4,5,6)\rangle$ and $C_2 := \langle(7,8)\rangle$ respectively. Therefore the full symmetry of Benzene as can be viewed clearly from figure 2, is: D_6 and D_2, which we can write in terms of direct product as $D_6 \times D_2$. We used GAP package to get the group as follows:

```
gap>
gap> c6 := DihedralGroup(IsGroup, 12);
Group([ (1,2,3,4,5,6), (2,6)(3,5) ])
gap> c2 := DihedralGroup(IsGroup, 2);
Group([ (1,2) ])
gap> DG := DirectProduct(c2,c6);
Group([ (1,2), (3,4,5,6,7,8), (4,8)(5,7) ])
gap>
gap> Order(DG);
24
gap>
gap> CC := ConjugacyClasses(DG);
[ ()^G, (4,8)(5,7)^G, (3,4)(5,8)(6,7)^G, (3,4,5,6,7,8)^G, (3,5,7)(4,6,8)^G, (3,6)(4,7)(5,8)^G]
gap>
gap> List(CC,x->Order(Representative(x)));
[ 1, 2, 2, 6, 3, 6]
gap>
gap> Display(CharacterTable(DG));;
gap>
gap>
```

Table 1: The Representatives of Conjugacy Classes for Benzene

S/N	Representatives	Size	Name
1.	(1)	1	$1a$
2.	(1,2)	2	$2a$
3.	(4,8)(5,7)	2	$2b$
4.	(3,5,7)(4,6,8)	2	$2c$
5.	(3,6)(4,7)(5,8)	2	$2d$
6.	(1,2)(3,5,7)(4,6,8)	6	$6c$

Table 2: Character Table for Benzene

	1a	2a	2b	6a	3a	2c
2P	1a	1a	1a	3a	3a	1a
3P	1a	2a	2b	2c	1a	2c
5P	1a	2a	2b	6a	3a	2c
X.1	1	1	1	1	1	1
X.2	1	-1	-1	1	1	1
X.3	1	-1	-1	1	1	1
X.4	1	-1	1	-1	1	-1
X.5	1	-1	1	-1	1	-1
X.6	1	1	-1	-1	1	-1

The character table of benzene is a tool that summarizes the symmetry properties of the molecule and its molecular orbitals. The character table has four columns: the symmetry operations, the classes, the characters, and the irreducible representations. The symmetry operations are the ways to transform the molecule into itself, such as rotations, reflections, and inversions. The classes are the groups of symmetry operations that have the same effect on the molecule. The characters are the numerical values that indicate how the molecular orbitals change under each symmetry operation. The irreducible representations are the labels that identify the symmetry types of the molecular orbitals.

The conjugacy classes of benzene are the subsets of the molecular orbitals that have the same symmetry type and energy. The conjugacy classes of benzene are Class containing the identity element (E): The identity element represents the absence of any symmetry operation. Class of rotations (C_6): Elements in this class are the rotations of benzene by multiples of 60°. There are six distinct rotations in this class. Class of reflections in the horizontal mirror plane (σ_h): Elements in this class are reflections of benzene in the horizontal mirror plane. Class of reflections in the vertical mirror planes (σ_v): Elements in this class are reflections of benzene in the six vertical mirror planes. Class of 2-fold rotations (C_2): Elements in this class are the 180-degree rotations. Class of 3-fold rotations (C_3): Elements in this class are the 120-degree rotations. The C_2 and C_3 classes are non-degenerate, meaning they have only one orbital each. The σ_h and σ_v classes are also non-degenerate, but they have different energies than the A1 and A2 classes. The E and C_6 classes are degenerate, meaning they have two orbitals each with the same energy.

The electronic transitions of benzene are the changes in the occupancy of the molecular orbitals due to the absorption or emission of photons. The electronic transitions of benzene can be predicted by using the character table and the conjugacy classes. The selection rules for the electronic transitions are:

i. The total symmetry of the initial and final states must be the same.

ii. The change in the number of nodes must be even.

iii. The change in the energy must match the energy of the photon.

Using these rules, we can determine which transitions are allowed and which are forbidden. For example, the transition from the E to the C_6 class is allowed, because the total symmetry is the same (E), the change in the number of nodes is even (2), and the change in the energy matches the energy of the photon. However, the transition from the σ_h to the C_3 class is forbidden, because the total symmetry is different (C_2 and σ_v), the change in the number of nodes is odd (1), and the change in the energy does not match the energy of the photon.

4. CONCLUSIONS

In this work, the symmetry operations of the Benzene molecule were studied. The conjugacy classes and the irreducible character tables of the molecules were computed as seen in table 1 and 2 using computational group theory. We found that the group is isomorphic to the Direct Product of $D_6 \times D_2$. and has order 24 and 9 conjugacy classes. We used GAP 4.11.1 for our calculations. Clearly, understanding the electronic transitions of benzene can provide insights into its electronic properties, which are important for many chemical and physical processes. Thus, symmetry can be applied in the prediction electronic transitions of benzene. Note, only orbitals that have the same irreducible representation have the correct symmetry to overlap and form a molecular orbital. It is natural to extend these methodologies to other aromatic molecules.

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ENERGY POVERTY IN THE ERA OF GLOBALIZATION: BRAZIL, CHINA AND INDIA

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ABSTRACT

In the contemporary era, marked by increasing globalization and technological innovation, the issue of energy poverty persists as a topic of debate in various parts of the world. In contrast to developed nations, developing countries face considerable challenges in meeting the growing demand for energy. With the aim of analyzing the role of financial inclusion and its impact on energy poverty in three representative countries in the global south —Brazil, China, and India—this article investigates disparities in electricity accessibility in these nations, examining them from the perspective of access as a human right. This article is dedicated to the analysis of the contribution of financial inclusion as a mitigating tool for energy poverty. The importance of energy in human subsistence is undeniable. Ensuring universal access to energy is not only a requirement to promote social well-being but also an imperative to drive the economic development of a nation. Within this context, the concept of energy poverty and its connection to renewable energy are addressed, taking into account both the human dimension and equity. To shape this research, a review of technical literature was conducted. This review emphasized the persistent inequality stemming from the distribution of income and energy as an urgent concern. However, there are indications that this disparity can be reduced through adjustments in energy tariff policies, grounded in research on socio-economic relations. In light of this purpose, this article aims to critically analyze the complex nuances of energy poverty. The research strives not only to mitigate the adverse effects of energy poverty but also to contribute significantly and comprehensively to the construction of a more inclusive future, where energy equity and sustainability are fundamental pillars. This proactive approach seeks to go beyond the mere identification of problems, actively aiming to be a driving force in promoting effective and lasting changes.

Keywords: Energy Poverty; Financial Inclusion; Renewable Energies; Brazil; China; India.

Introduction

The concept of energy poverty is broad and involves different dimensions. The Economic Commission for Latin America and the Caribbean (ECLAC) considers energy poverty to occur when a household lacks equitable access to adequate, reliable, efficient, and safe energy services to cover its basic needs. These services should enable sustaining human and economic life, developing household members, and the energy bill should not exceed 10% of their income (ECLAC, 2014). On the other hand, the European Commission defines energy poverty as when a household has to reduce its energy consumption to a level that has a negative impact on the health and well-being of its residents (European Commission, 2023). Among various definitions, this work adopts the definition of the International Energy Agency (OECD/IEA, 2016), characterizing energy poverty as a lack of access to modern energy sources, such as electricity, condemning the population to dependence on locally available resources, usually wood, with its limitations in energy efficiency and usage, leading to economic, environmental, and health consequences.

According to the 2017 World Energy Outlook report, providing modern, safe, and accessible energy to all citizens contributes to economic growth and poverty reduction. Historically, economic advancement has largely resulted from the shift from agrarian to industrial economies, altering energy consumption patterns (IEA, 2017). Thus, there is a direct relationship between access and use of modern energy sources and economic and social development (Pereıra, Vasconcelos, and Sılva, 2011).

It is essential to note that the United Nations (UN) and its 193 Member States have agreed to a plan to achieve 17 Sustainable Development Goals (SDGs) by 2030, aiming for societies without poverty and hunger, with quality of life and social inclusion, without overburdening the planet. SDG 7 specifically addresses ensuring access to reliable, sustainable, and modern energy for all (UN Brazil, 2022).

According to the findings of the 2022 edition of the specialized report tracking progress towards Sustainable Development Goal 7 (SDG 7), titled "Tracking SDG 7: The Energy Progress Report"[1], 733 million people worldwide lack access to electricity, and 2.4 billion people still cook using health and environmentally harmful fuels. This study, conducted by the World Bank, World Health Organization (WHO), United Nations Statistics Division (UNSD), and other partners like the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA), warns that, according to its conclusions, maintaining the current pace of progress will leave 670 million people without electricity by 2030, an increase of 10 million from the previous year's estimate.

Despite the survey indicating progress in the proportion of the global population with access to electricity – increasing from 83% in 2010 to 91% in 2020 – achieving the set target for 2030 requires an increase in the number of new connections to 100 million per year. If the current pace is maintained, the world will reach only 92% electrification (United Nations Brazil, 2022).

This article aims to be a driving force in promoting effective and lasting changes, encouraging the implementation of energy policies that consider socioeconomic relationships, aiming to reduce persistent inequality in income and energy distribution. By connecting the concepts of energy poverty, financial inclusion, and the role of renewable energy, the research not only highlights the urgent concern with this disparity but, above all, seeks a future where energy equity and sustainability are fundamental pillars. Through this integrated approach, the article aims to contribute to a more just global scenario, where access to energy and the implementation of sustainable sources not only reduce energy poverty but also promote financial inclusion and socioeconomic development in the specific contexts of Brazil, China, and India.

Materials and Methods

This study employed a methodology involving the collection and analysis of data through a literature review of technical literature and access to statistical databases from the Statistical Review of World Energy by the Energy Institute, covering the years 2020 to 2022. Growth rates, participation, and trends in renewable energy consumption were examined for these countries. Additionally, supplementary literature review compared the

[1] The document "Tracking SDG 7: The Energy Progress Report" monitors global efforts to ensure the provision of modern and accessible energy for all by 2030.

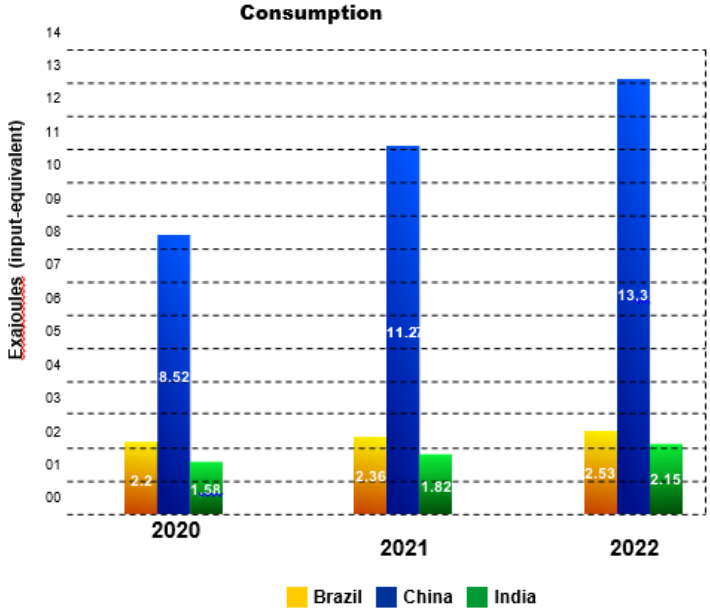
trajectories of Brazil, China, and India, providing insights into implications for energy policies, socio-economic development, and sustainability.

Findings and Discussion

According to the data presented by the Statistical Review of World Energy, there has been a notable increase in the global scenario of renewable energy consumption and generation in recent years. Key countries such as Brazil, China, and India have experienced significant progress in this scenario. The data indicates a consistent growth trajectory towards more sustainable and cleaner sources. Globalization is intrinsically linked to the energy market, exerting an impact on the issue of energy poverty (Zhao et al., 2022).

The analysis of the relationship between renewable energy consumption and energy poverty is investigated by Zhao et al. (2022). Figure 1 presents data on renewable energy consumption in Exajoules for the years 2020, 2021, and 2022 in the three countries covered. Brazil stands out for its growth, increasing from 2.2 Exajoules in 2020 to 2.53 Exajoules in 2022, highlighting the country's ongoing commitment to more sustainable sources. China leads in absolute consumption, with a notable increase from 8.52 Exajoules in 2020 to 13.3 Exajoules in 2022. India also records significant growth, going from 1.58 Exajoules in 2020 to 2.15 Exajoules in 2022, indicating a similar commitment to renewable sources.

Figure 1. Renewable Energy Consumption



Source: Own elaboration based on data from Energy Institute.

Statistical Review of World Energy (EI,2023).

When comparing the three countries, China leads in absolute terms, followed by Brazil and India. Despite the more modest consumption of the latter two, there is a clear positive trend in growth, indicating a global movement towards more sustainable energy practices. This transition to renewable sources not only contributes to mitigating climate change but also has direct implications for reducing energy poverty and promoting financial inclusion. Therefore, the eradication of energy poverty emerges as an essential catalyst for establishing a balance between the domains of economic, social, and environmental development. Such an approach aligns harmoniously with the Sustainable Development Goals outlined by the United Nations, as highlighted by Alola(2019) and Li(2014).

Zhang et al. (2022) conduct an investigation into the determinants of energy poverty through the analysis of renewable energy consumption. Table 1 provides a comprehensive description of renewable energy consumption, addressing both annual growth in exajoules and the percentage share in the years 2020, 2021, and 2022. The data arrangement is organized by country, with a particular focus on trends observed in Brazil,

China, and India. In Brazil, consumption started at 2.2 exajoules in 2020, reaching 2.36 in 2021 and 2.53 in 2022, with an annual growth rate of 7.2%. Additionally, the percentage share of total energy consumption reached 5.6% in 2022. China recorded a notable increase, rising from 8.52 exajoules in 2020 to 13.3 in 2022, with an annual growth of 18.1% and a significant share of 29.4% in total consumption in 2022. India also showed consistent growth, going from 1.58 exajoules in 2020 to 2.15 in 2022, with an annual increase of 18%, and a share of 4.8% in total energy consumption in 2022.

Table 1. Evolution of Renewable Energy Consumption (2020-2022)

Exajoules (input-equivalent)				Growth rate per annum	Share
COUNTRIES	**2020**	**2021**	**2022**	**2022**	**2022**
BRAZIL	2.2	2.36	2.53	7.2%	5.6%
CHINA	8.52	11.27	13.3	18.1%	29.4%
INDIA	**1.58**	**1.82**	**2.15**	**18%**	**4.8%**

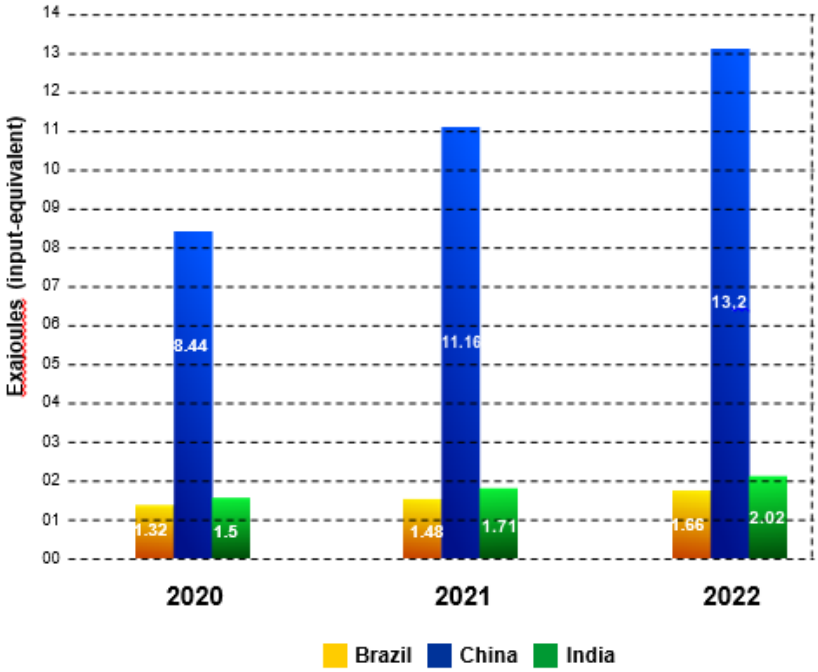
Source: Own elaboration based on data from Energy Institute.

Statistical Review of World Energy (EI,2023) .

Groh and Taylor (2017) emphasize the crucial importance of financial inclusion in the implementation of renewable energy generation (Khan, 2023). The analysis of trends in renewable energy generation in the years 2020, 2021, and 2022 for Brazil, China, and India was conducted based on data from the Energy Institute, as detailed in the source Statistical Review of World Energy (EI, 2023).

Continuing this perspective, Figure 2 highlights the landscape in 2022, revealing that Brazil had a renewable energy generation of 1.32 exajoules, with increases to 1.48 in 2021 and 1.66 in 2022. This progress reflects a clear positive trend in the adoption of sustainable energy sources over this period. In the Chinese context, renewable energy generation was notably more significant, starting at 8.44 exajoules in 2020, growing to 11.16 in 2021, and reaching 13.2 in 2022. These values emphasize China's significant contribution to the global landscape of renewable energy generation, highlighting its prominent role in this sector. Regarding India, a consistent increase in renewable energy generation was observed, starting from 1.5 exajoules in 2020, rising to 1.71 in 2021, and reaching 2.02 in 2022. This growth reflects the country's efforts to intensify the use of sustainable energy sources as part of its approach to addressing energy challenges. These data provide a comprehensive perspective on renewable energy generation in the mentioned years for Brazil, China, and India, highlighting the distinct dynamics shaping the renewable energy sector in each country.

Figure 2. Renewable Energy Generation



Source: Own elaboration based on data from Energy Institute.

Statistical Review of World Energy (EI,2023).

These numbers highlight the commitment of these three nations to move towards a more sustainable future, where renewable energy plays a crucial role in the global energy matrix. The consistent growth and substantial contributions of these nations underscore the ongoing need for investments and innovations in the energy sector, aiming for a transition to cleaner and renewable sources on a global scale.

Table 2, titled "Evolution of Renewable Energy Generation," presents information on the annual growth and percentage share in renewable energy generation for the years 2020, 2021, and 2022 for Brazil, China, and India. In Brazil, generation started at 1.32 exajoules in 2020, increased to 1.48 in 2021, and reached 1.66 in 2022. The annual growth rate was 11.9%, while the percentage share in total energy generation in 2022 was 4.1%. These data were compiled based on information from the Energy Institute and are detailed in the source Statistical Review of World Energy (EI, 2023).

In China, renewable energy generation was substantially higher, starting at 8.44 exajoules in 2020, reaching 11.16 in 2021, and hitting 13.2 in 2022. The annual growth was 18.3%, and the percentage share in total energy generation in 2022 was remarkable, reaching 32.3%. Finally, India also recorded consistent growth in renewable energy generation, starting from 1.5 exajoules in 2020, rising to 1.71 in 2021, and reaching 2.02 in 2022. The annual growth was 18.2%, and the percentage share in total energy generation in 2022 was 4.9%. These data provide a comprehensive insight into the evolution of renewable energy generation in these countries, highlighting the distinct dynamics of this sector.

Table 2. Evolution of Renewable Energy Generation (2020-2022)

Exajoules (input-equivalent)				Growth rate per annum	Share
COUNTRIES	**2020**	**2021**	**2022**	**2022**	**2022**
BRAZIL	1.32	1.48	1.66	11.9%	4.1%
CHINA	8.44	11.16	13.2	18.3%	32.3%
INDIA	**1.5**	**1.71**	**2.02**	**18.2%**	**4.9%**

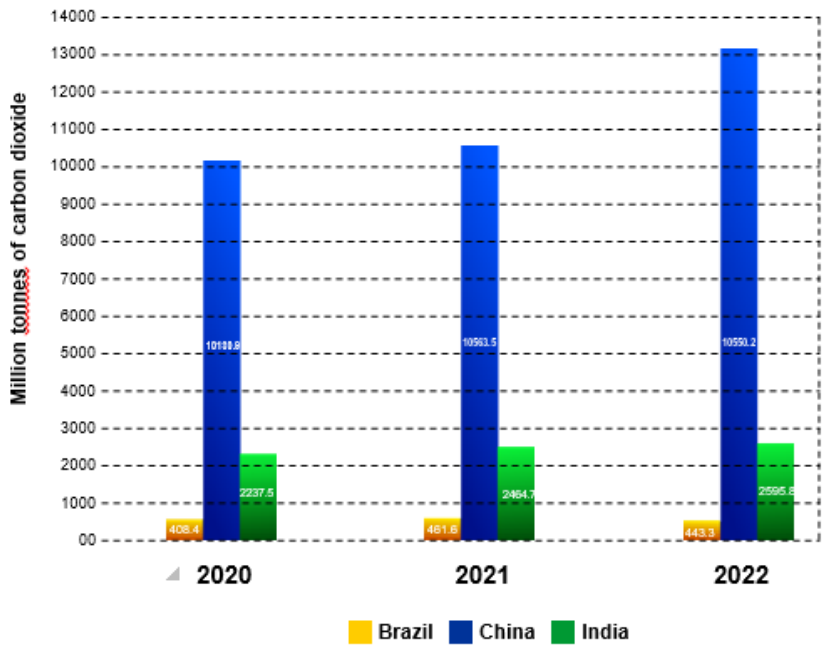
Source: Own elaboration based on data from Energy Institute.

Statistical Review of World Energy (EI,2023).

In summary, Table 2 reveals distinct growth patterns in the three countries, highlighting diverse approaches in their trajectories towards more sustainable energy practices. While Brazil maintains a steady progression, China and India exhibit more significant rates, demonstrating the complexity and diversity of strategies adopted by each nation to drive the transition to renewable energy sources. This diversity of approaches in renewable energy generation underscores the importance of a comprehensive analysis to understand annual trends.

In this context, Figure 3 complements the analysis by providing specific data on carbon dioxide emissions in millions of tons for Brazil, China, and India in the years 2020, 2021, and 2022. In Brazil, emissions were 408.4 million tons in 2020, increased to 461.6 in 2021, and subsequently decreased to 443.3 in 2022. This dataset highlights the variability in CO2 emissions over these years. In China, emissions were notably higher, starting at 10130.9 million tons in 2020, rising to 10563.5 in 2021, and remaining virtually stable at 10550.2 in 2022. This pattern suggests a significant presence of China in global CO2 emissions, emphasizing the importance of sustainable strategies in this scenario. Lastly, India recorded an increase in emissions, starting from 2237.5 million tons in 2020, rising to 2464.7 in 2021, and reaching 2595.8 in 2022. These data provide valuable insights into the trends in CO2 emissions for these countries over the mentioned years.

Figure 3. Carbon Dioxide Emissions from Energy



Source: Own elaboration based on data from Energy Institute.

Statistical Review of World Energy (EI,2023).

Table 3, titled "Evolution of CO2 Emissions from Energy," provides a detailed analysis of CO2 emissions in the years 2020, 2021, and 2022, including annual growth rates and the percentage share in 2022 for Brazil, China, and India. In Brazil, emissions started at 408.4 million tons in 2020, increased to 461.6 in 2021, and decreased to 443.3 in 2022, reflecting a -4% annual growth rate, with a percentage share in global emissions of 1.3% in 2022.

In contrast, China showed relative stability in its CO2 emissions, recording a slight decrease of 0.1% in 2022 compared to the previous year. Despite this modest reduction, China remains the top emitter, contributing significantly with 10,550.2 million tons in 2022. As a global leader, the country faces considerable challenges in emission reduction, and the observed stability can be interpreted as an indication of control and dedicated efforts to mitigate environmental impacts.

This stability in CO2 emissions in China not only suggests relative control over emissions but also highlights the importance of addressing challenges related to financial inclusion during the transition to more sustainable sources. Ensuring that all segments of society have access to economic opportunities associated with the energy transition is essential to avoid disparities and promote effective financial inclusion.

Table 3. Evolution of CO2 Emissions from Energy (2020-2022)

	Million tonnes of CO2			Growth rate per annum	Share
COUNTRIES	**2020**	**2021**	**2022**	**2022**	**2022**
BRAZIL	408.4	461.6	443.3	-4%	1.3%
CHINA	10130.9	10563.5	10550.2	-0.1%	30.7%
INDIA	**2237.5**	**2464.7**	**2595.8**	**5.3%**	**7.6%**

Source: Own elaboration based on data from Energy Institute.

Statistical Review of World Energy (EI,2023).

The analysis of CO2 emissions from energy in recent years reveals distinct approaches adopted by Brazil, China, and India. Considering the data presented in Table 3, it is evident that Brazil, despite experiencing fluctuations in its emissions, has shown an overall trend of reduction, reflected in a 4% decrease in emissions from 2021 to 2022. This pattern suggests possible efforts to implement more sustainable practices and reduce the carbon footprint in the Brazilian energy sector.

On the other hand, China, despite a slight decrease of 0.1% in 2022, remains a significant player in global emissions, contributing a substantial amount of 10,550.2 million tons in 2022. The challenge for China lies in balancing its position as a global leader with the need to reduce emissions. The observed stability can be interpreted as an indication of control and dedicated efforts to mitigate environmental impacts, although there is a continuous need to address challenges related to financial inclusion during the transition to more sustainable sources. Ensuring that all segments of society have equitable access to economic opportunities associated with the energy transition is crucial to avoid disparities and promote effective financial inclusion in the context of climate change.

Conclusion and Recommendations

The research explored the issue of energy poverty in countries in the global south such as Brazil, China, and India, examining the influence of financial inclusion on access to energy. The analysis identified various trends and challenges, emphasizing the complexity of interactions between energy poverty, financial inclusion, the adoption of renewable energy, and CO2 emissions. Several factors, such as globalization, climate change, and financial inclusion, were highlighted as significant determinants of energy poverty (ZHAO et al., 2022).

One notable conclusion was the significant progress in renewable energy consumption by these countries. Brazil, China, and India demonstrated a clear commitment to cleaner and more sustainable sources, contributing substantially to the global renewable energy landscape. The relationship between renewable energy consumption and energy poverty is fundamental, as emphasized by Zhang et al. (2022). However, when

analyzing CO2 emissions, it was observed that while Brazil succeeded in reducing its emissions, China faced significant challenges as the main global emitter, and India, in turn, recorded an increase, highlighting the complex interaction between economic growth and environmental responsibility.

Amidst these findings, the interconnection between socioeconomic and environmental challenges becomes evident. Promoting investments in sustainable technologies, developing inclusive policies, educating and raising awareness about sustainable practices, international cooperation, and ongoing policy assessment are essential to address these challenges in an integrated manner.

By adopting these recommendations, governments and private sectors can not only address energy poverty but also drive inclusive and environmentally sustainable development in the economies of countries in the global south, contributing to a more equitable and resilient future.

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EXPLORING SMART WORK'S IMPACT ON SUSTAINABILITY: A BIBLIOMETRIC ANALYSIS

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ABSTRACT

The main purpose of this study is to provide a comprehensive overview of the impact of smart working on sustainability. By highlighting the challenges and opportunities associated with optimizing the use of energy resources and promoting sustainable behaviors within organizational contexts, this research aims to shed light on the multifaceted impacts that smart working practices can have on environmental sustainability. A goal-oriented work organization, with flexible schedules and locations, indeed brings benefits not only to organizations but also to the environment. This study attempts to outline practical recommendations aimed at promoting the implementation of remote work practices that significantly contribute to a more sustainable future. These inquiries seek to unveil the current breadth and depth of research in the field of smart working and sustainability, identify influential figures and seminal works that shape this discourse, and track the evolution of keywords and thematic elements in relation to the outlined topics. Therefore, the authors have formulated specific research inquiries guiding the bibliometric study: What is the current scope and depth of research concerning the correlation between smart working and sustainability? Who are the influential authors and pivotal articles in this field? How have the keywords and thematic elements evolved concerning our outlined topics? Some responses stem from our scrutiny of existing literature on sustainability, while others derive from broader academic works or practical discourse. Our analysis confirms the escalating interest in this subject and marks an initial exploratory phase in the literature study, there-by charting the course for future research endeavors.

Keywords: smart working, organizations, sustainability, energy.

Introduction

The intersection between smart working and sustainability represents a multifaceted arena encompassing business dynamics, workforce evolution, and environmental concerns. Smart working, especially in the context of the COVID-19 pandemic, has catalyzed substantial shifts in work methodologies, fostering the integration of digital technologies into daily operations (HyunJung et al., 2022). This transformative phase significantly influences both the workforce and the environment, reshaping work-life integration, stress paradigms, and energy consumption patterns (Palm et al., 2020). Additionally, the incorporation of smart working practices within human resource policies assumes a pivotal role in shaping workforce sustainability, particularly in remote or geographically isolated settings (Onnis, 2017).

Beyond its impact on the workforce, smart working holds implications for environmental sustainability. The emergence of sustainable smart product-service systems stands as a critical linchpin in understanding how smart working practices contribute to broader sustainability goals (Ries et al., 2023). Furthermore, the concept

of smart sustainable urban development intimately intertwines with the integration of smart working practices and their implications for urban landscapes (Natalia et al., 2021). This interconnectedness paints a complex landscape demanding comprehensive comprehension—spanning workforce dynamics, business modalities, and environmental ramifications—to enable organizations to strategize the maximization of smart working advantages while mitigating potential sustainability drawbacks.

The surge in remote work, synonymous with teleworking or smart workinging, has surged, especially during the COVID-19 era. Various studies have delved into the correlations and consequences of remote work on diverse facets such as well-being, work-life equilibrium, productivity, and job satisfaction (Felstead & Henseke, 2017). The findings unveil a nexus between remote work and heightened organizational commitment, job satisfaction, and work-related well-being. Yet, this comes at the cost of intensified workloads and a challenge in disconnecting from work (Felstead & Henseke, 2017). Similarly, Rachman et al. (2022) underscore that remote work fails to moderate the correlation between employee engagement and creativity, emphasizing the necessity for employee empowerment to catalyze creativity (Rachman et al., 2022).

The burgeoning recognition of digital trasformation's potential to bolster sustainability spans diverse sectors. In agriculture, the deployment of digital trasformation significantly contributes to sustainable farming practices, curbing environmental degradation while enhancing productivity and cost efficiency (Santiteerakul et al., 2020; Musa et al., 2021). Furthermore, the realm of smart logistics—digital trasformation implementation in logistics and freight transport—holds promise for influencing the sustainability landscape of smart cities, albeit with underexplored dimensions (Shee et al., 2021). Moreover, the application of smart contracts in supply chain management presents a paradoxical relationship with environmental sustainability, necessitating deeper investigation (Groschopf et al., 2021).

Across diverse industries, the adoption of smart working as a sustainable human resource practice is increasingly observed. For instance, within the tourism sector, the convergence of information technology development and sustainability concerns propels the uptake of smart working practices (HyunJung et al., 2022). Public organizations also leverage smart working practices to foster collaborative innovation, anchoring sustainability within their vision for innovation and governance (Romanelli, 2022). Notably, the symbiosis between eco-innovation and smart working accentuates the potential for sustainable management, showcasing how innovative leadership can drive economic sustainability via smart working implementation (Bucea-Manea-Tonis et al., 2021). Furthermore, the pivotal role of digital trasformation in attaining sustainable competitiveness underscores the necessity for nuanced exploration into its implementation as a management strategy (Ejaz, 2023). Additionally, the nexus between favorable workplace conditions, firm financial performance, and environmental sustainability underscores the need to address employee health, safety, and welfare for holistic workplace sustainability (Zahid et al., 2021). The amalgamation of digital trasformation and smart workinging practices presents a promising avenue to bolster sustainability across multiple sectors. However, a deeper dive into the implications and potential challenges surrounding their adoption within the sustainability context warrants further scholarly investigation.

Building upon these insights, our work aims to scrutinize the interconnectedness of smart workinging and sustainability. Hence, we pose the central research question: To what extent and in what dimensions has existing literature scrutinized the relationship between smart working and sustainability? To address this, we conducted a comprehensive bibliometric analysis to map the international academic discourse on these topics. This study delves into specific research questions, focusing on:

RQ1: The current depth and analysis of research concerning the relationship between smart working and energy sustainability.

RQ2: Identification of the most influential authors and articles in this domain.

RQ3: The evolution of keywords and themes pertinent to smart working and energy sustainability.

This study intends to elucidate the evolutionary trajectory of this discourse, identifying its current status and paving the way for future developments (Aria & Cuccurullo, 2017). Our bibliometric analysis spans literature from 1996 to 2023 retrieved from the Web of Science, encompassing 247 papers across 168 journals. Notably, the majority of studies, approximately 80%, surfaced within the last three years, with 30% originating solely within the last year. This burgeoning trend underscores the vibrancy and growth of our topic. Despite the prevalence of virtual teams in contemporary work landscapes, a comprehensive understanding of the interplay between smart working and sustainability within these teams remains a fertile ground for exploration. This

analysis is poised to offer valuable insights into the current research landscape, identifying gaps and potential avenues for future inquiry. The subsequent sections of this paper encompass: Section 2 detailing the methodology, database, and analytical tools employed; Section 3 presenting and interpreting results through structured tables and figures; and Section 4 offering conclusions, limitations, and avenues for future research.

Materials and Methods

This study aims to determine, through a bibliometric analysis, the extent to which the literature has examined the relationship between energetic sustainability and smart working contexts up to the present day. Bibliometric analysis can divide the time span into several time periods to capture the evolution of the field through time. It is carried out at a specific point in time to represent a static picture of the field at that time (Escobar et al., 2021). We conducted a bibliometric analysis on the theme of energetic sustainability and smart working following Aria & Cuccurullo (Aria & Cuccurullo, 2017). Bibliometrix it provides an intuitive user interface and the ability to extract bibliometric networks using a variety of units of analysis, including citations, authors, countries, and keywords (Moral-Muñoz et al., 2020). A typical workflow consists of the following five steps (Zupic & Carter, 2015): study design; data collection; data analysis; data visualization; interpretation (Aria & Cuccurullo, 2017). In study design, academics specify the research question(s) and select the bibliometric techniques that will best address the question(s). Scholars choose the database that houses the bibliometric data, filter the core document set, and export the data from the chosen database during the data collection process. This step can entail building one's own database (Waltman, 2016). One or more bibliometric or statistical software tools are used for data analysis. As an alternative, students might create their own computer code to satisfy their needs. Data visualization is done in the fourth stage. Researchers must choose the visualization technique to apply to the third-step results before using the right mapping software. The final step is interpretation, during which researchers explain and interpret their findings. Even though bibliometric tools frequently disclose a field's structure in a different way than standard literature evaluations, they do not replace in-depth reading in the area. Researchers who are well-versed in the subject have an obvious competitive advantage. The second through fourth phases, which comprise many sub-stages, are often supported by software. Tools for conducting quantitative bibliometric and scientometric research are available through the bibliometrix R-package (http://www.bibliometrix.org). It is written in the open-source R language, which has an ecosystem. The main reasons to choose R over other languages for scientific computation are probably the availability of robust, efficient statistical algorithms, availability of top-notch numerical routines, and integrated data visualization capabilities (Aria & Cuccurullo, 2017). Performance analysis and science mapping are the two main applications of bibliometric approaches (Cobo et al., 2011). Performance analysis is to assess the research and publication output of organizations and people. Science mapping seeks to show how scientific domains are structured and evolving. The researcher can utilize this structure and development information to review a specific area of inquiry. Bibliometric techniques provide the subjective criticism of literature a quantitative edge. In a review article, they can offer proof of theoretically derived categories (Aria & Cuccurullo, 2017). More specifically, our study initiates with a preliminary investigation, known as too a scoping exercise. This step encompasses the identification of an appropriate database, selecting pertinent keywords, and the study's time frame. The selection of the database was determined based on the available literature. Specific authors assert that WoS possesses the most significant quantity of esteemed journals and articles (Ball & Tunger, 2006) necessitating reduced data-cleansing procedures (Zupic & Carter, 2015). To achieve the objective of the work, we searched in a scientific database with the help of a query. The scoping exercise focused on the keywords Sustainability AND Smart Working. Our search string in the WoS database was Topic TS= (("sustainab*" or energ* or "energ* saving" or "environm* impact") and ("smart work*" or "remote working" or "teleworking")) 1996-2023, refined:

– by including Web of Science all categories (Citation Topics Meso)

– by including languages: (English)

– by including citations Indexes: SSCI; ESCI; SCI-EXPANDED, BKCI-SSH;

BKCI-S.

In total, we obtained 247 papers form the search process. This data file was afterwards imported to Bibliometrix software. These networks may, for instance, include journals, researchers, or individual publications, and they

can be constructed based on citation, bibliographic coupling, co-citation, or co-authorship relations" (Aria & Cuccurullo, 2017).

Findings and Discussion

Descriptive analysis: Publication trends

We extracted from WoS 247 documents (see Fig. 1). Then we carried out the bibliometric analysis using the Bibliometrix R-package version 4.1.2 (http://www.bibliometrix.org) (Aria & Cuccurullo, 2017). Examination opens by presenting the focal material about data (see Fig. 1). Figure 1 describes the key information about data. The bibliometric analysis of our sample covers a period from 1996 (the year of a previous publication) to 2023. A total of 247 documents emerges from the analysis. Most of these are scientific articles published in journals, 168 are different sources. Most articles have been co-written; in fact, the collaboration index is exceedingly high (3.81); the Collaboration Index (CI) is calculated as Total Authors of Multi-Authored Articles/Total Multi-Authored Articles (Koseoglu, 2020; Elango & Rajendran, 2012). In other word, the Collaboration Index is a Co-authors per Article index calculated only using the multi-authored article set. Finally, the number of citations is around 24 per paper.

Fig. 1. Main Information.

Figure 2 shows the publication trend in the topic area. Until 2015, there were just two or three publications per year on smart working and sustainability. In 2019, started an important trend in the discussion, but interest did not really expand until 2020.

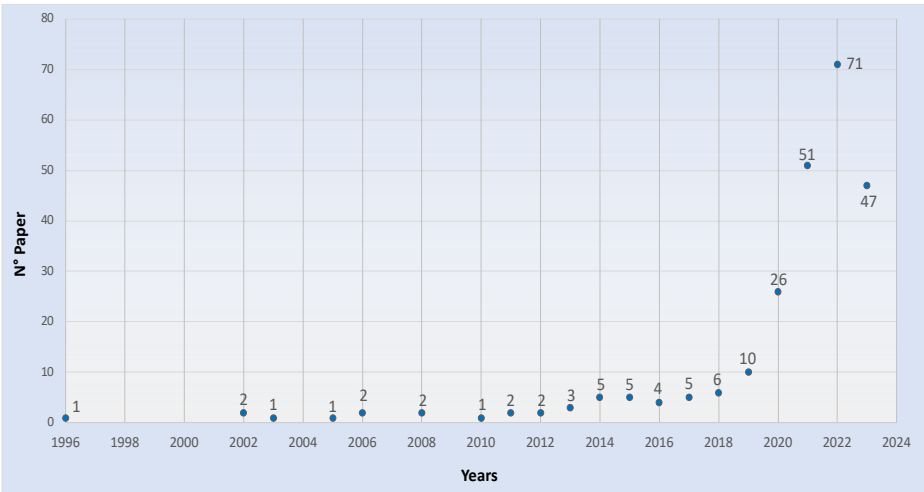

Fig. 2. Annual Scientific Production

Sources

This section provides an overview of the research findings derived from the articles included in this study, focusing on the source's scope (Büyükkıdık, 2022). Table (1) shows that only one source has published more than four articles on this topic. Thus, there is, excluding the journal "Sustainability" no dominant source of articles on smart working and sustainability.

Table 1. Most relevant Sources.

Sources	Articles
Sustainability	47
Energy and Buildings	4
Journal of Cleaner Production	4
Transportation Research Record	4
Frontiers In Psychology	3
International Journal of Environmental Research and Public Health	3
Transport Policy	3
Transportation Research Part A-Policy and Practice	3
Travel Behaviour and Society	3
Applied Sciences-Basel	2

Table 2 shows the 'Most Local Cited Sources'. The local citation is an important indicator of the significance and influence of a source within a specific academic context (Aria & Cuccurullo, 2017). In the context of the mentioned analysis, the two most frequently cited journals are the "Sustainability-basel" and the "Transportation Research Part A: Policy and Practice ". This information suggests that articles published in these journals are considered relevant and influential in the fields of sustainability management. The frequency of citations indicates that scholars and academics working in these fields deem the articles published in these journals to be valuable contributions to the existing body of knowledge (Aria & Cuccurullo, 2017).

Table 2. Most Local Cited Sources.

Sources	Articles
Sustainability-basel	302
Transport Res A-Pol	178
Journal of Cleaner Production	158
New Tech Work Employ	146
Journal Appl Psychol	144
Energ Buildings	121
Inter. J. Env Res Pub He	109
Journal Organization Behavior	105
Transportation	105
Journal Transp Geogr	100

Most relevant authors, Affiliations and Countries

The findings of the analyzes of the authors conducting research related to smart working and sustainability were handled in this section.

The analysis of authors' relevance shows an interesting pattern (see Table 3). O'Brien is the only author to have published more than three contributions on this topic. All other authors have either two or, at most, three publications on the topic. This highlights the potential for future research and collaboration. It may be worth investigating the factors that limit other authors' publication output, such as competing research interests or resource constraints.

Table 3. Most Relevant Authors in the field.

Authors	Articles
O'Brien W.	5
Manuti A.	3
Sorrell S.	3
Anderson R.J.	2
Campisi T.	2
De Witte A.	2
Edwards D.J.	2
Ghislieri C.	2
Giancaspro M.l.	2
Graham D.J.	2

In research evaluation, it is crucial to consider both quantitative and qualitative aspects, because they provide complementary perspectives within a specific research field. We therefore also extracted the most locally cited authors, to provide an insight into which authors are most frequently referenced in this field, and therefore the qualitative value of their contributions (see Figure 3). The function citations generate the frequency table of the most cited references or the most cited first authors (of references). Interestingly, Sorrel work seems to hold a higher qualitative value than O'Brien, despite the fact that the latter have a higher number of publications. Sorrel ranking as the most locally cited author suggests that their work has substantial recognition and influence within the field. This implies that her publications are highly regarded and have made significant contributions to the advancement of knowledge in the subject area. This finding emphasizes the importance of not solely relying on quantitative measures, such as publication count when assessing the impact and quality of an author's work. In conclusion, O'Brien is more prolific, but the local citations show that Sorrel qualitative value is more significant within the academic community.

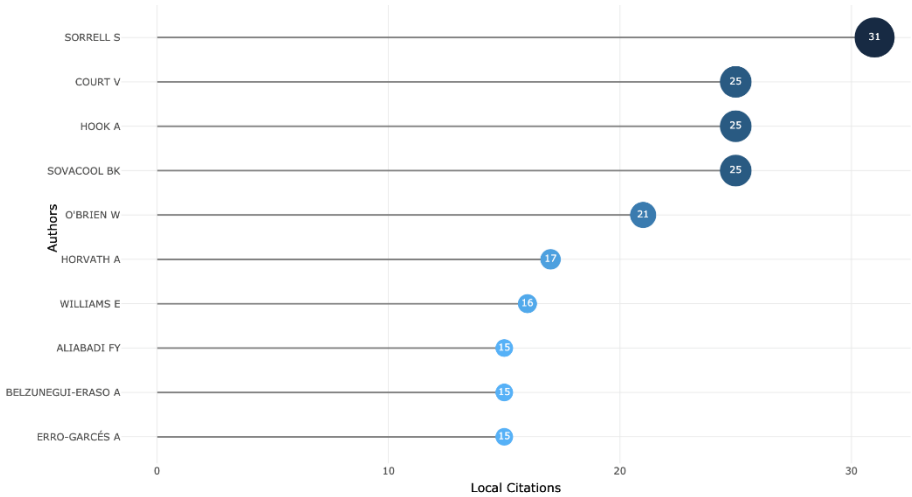

Fig. 3. Most Local Cited Authors.

Our descriptive analysis moves on with the study of research centres (see Figure 4). That is, those universities where the topic is strongly analysed and able to increase the know-how of those interested in the matter under analysis.

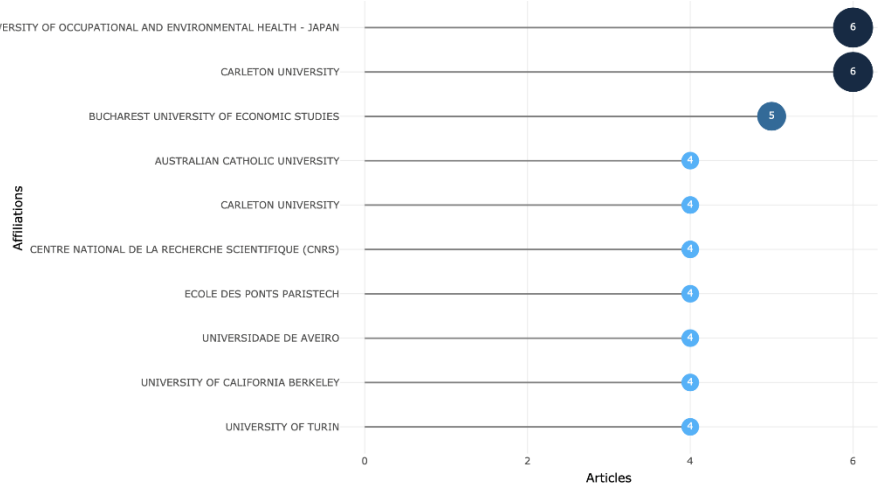

Fig. 4. Most Relevant Affiliations.

This scientific analysis provides insights into the publication productivity and impact of the top 10 countries in the research topic (Table 4). The data presented in the table highlights the Italy as the most productive country, with the highest number of publications in the field followed by United Kingdom and United States. This indicates the strong research output and presence of the Italy in the research community for the given topic.

Table 4. Countries' Scientific Production

Region	Freq
Italy	77
Uk	57
Usa	43
Australia	36
Canada	32
France	32
China	27
Spain	26
Portugal	23
Romania	21

Moreover, the assessment of impact based on citations (see Tab. 5) reveals that the Spain leads in terms of citations, indicating that research originating from the Spain has garnered substantial attention and influence within the academic community. The presence of the United Kingdom and United States as the countries with the second and third highest number of citations, respectively, indicates their significant contributions and impact in the field as well. These tables put in evidence articles that are a reference for international literature, measuring this aspect through citations.

Table 5. Most Cited Countries.

Country	TC
SPAIN	545
UNITED KINGDOM	413
USA	361
ITALY	332
INDIA	131
ROMANIA	131
GREECE	124
SWEDEN	112
CANADA	106
AUSTRALIA	102

Most relevant documents, words and trending topics

In the first part of this section, we look at the different measures of citation impact for academic publications. These measures help evaluate the influence and importance of research articles within a specific context.

The first ranking denoted as "Most Global Cited Documents" represents the articles that have garnered the highest overall citation count across various sources and disciplines. These articles can be considered highly influential within the broader scientific community (see Figure 5).

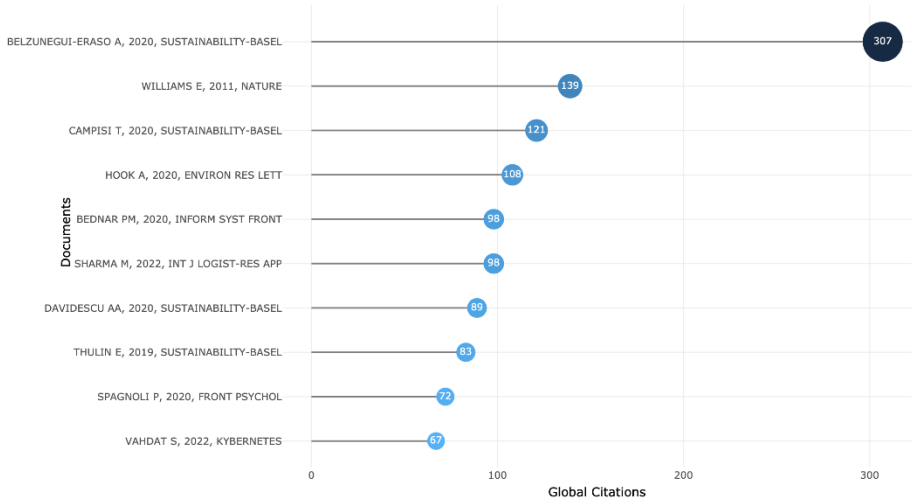

Fig. 5. Most Global Cited Documents.

On the other hand, the second ranking, referred to as "Most Local Cited Documents", refers to the ranking of documents based on their citations within a specific discipline and field (see Figure 6). It focuses on citations from a particular set of sources or a specific community of researchers. Figure 6 highlights the specific impact of two articles by Hook *et al.* and Belzunegui *et al.* within the context of our topic. These two groups of authors are responsible for producing the most influential articles identified so far on our field.

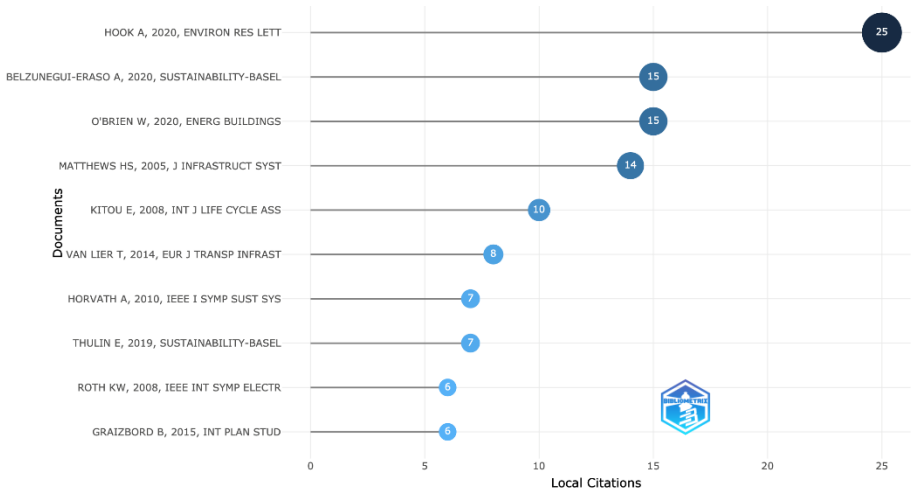

Fig. 6. Most Local Cited Documents

In addition, we used Keywords Plus to develop a tree map of the most relevant topics (Figure 7). We excluded 'teleworking' and 'study' to show that the most frequently used words beyond these central terms was 'energy". This suggests that most studies in this field focus on energy study, followed by 'pandemic', 'covid' and 'remote'. The next-most frequently used terms were 'results', 'research' and 'employees', all fundamental issues within this topic.

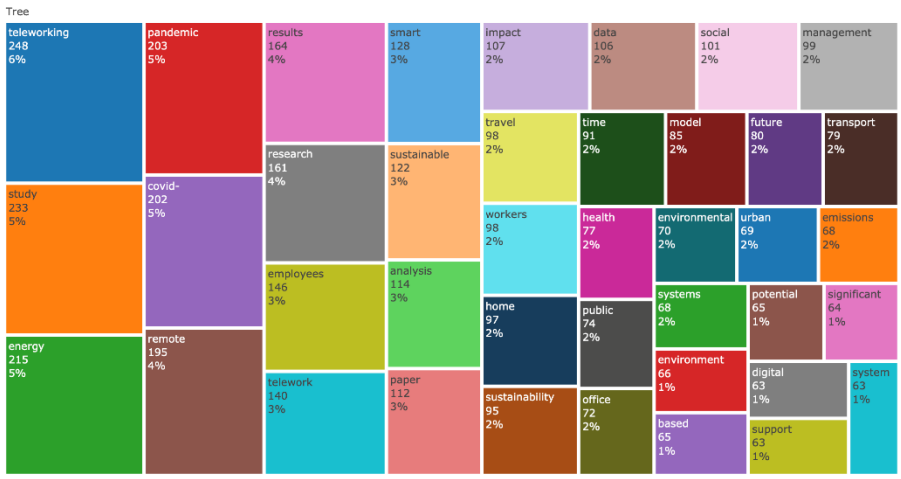

Fig. 7. Tree Map Keywords Plus

Figure 8 shows that the majority of these keywords started to emerge in the research landscape around 2004, and their use has experienced consistent growth since then. Until 2018, the prevalence of the keywords remained relatively stable, with the exception of 'energy', 'telework' and 'teleworking'. However, from 2019 - 2020, all the keywords showed a noticeable upward trend, indicating a gradual increase in their use. This gradual increase could also be attributed to a greater recognition of the importance of these themes and the need for further exploration to better understand related social, scientific, or technological phenomena.

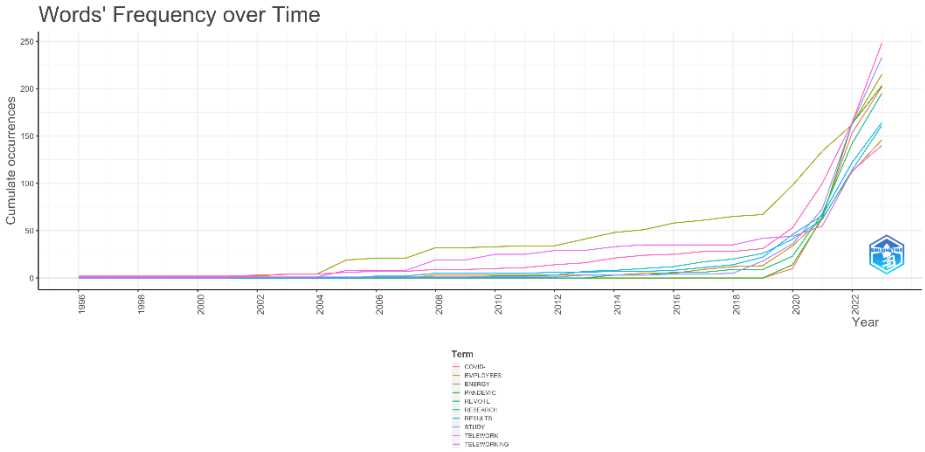

Fig. 8. Word's Frequency over Time (field)

Knowledge Structure: Conceptual and Social:

The analysis now shifts to the structure of knowledge, specifically, to the Conceptual and Social analysis. The conceptual structure allows us to create clusters capable of separating topics. By creating clusters, researchers can group related publications together and identify distinct research topics or areas of interest within a field. This can help in understanding the structure of knowledge and the relationships between different research areas (see Fig. 9). In this specific case, Bibliometrix generated five major clusters:

- blue cluster takes performance into account and is closely linked to sustainability and work. It has been determined that this particular cluster holds the utmost significance in the study context. Blue cluster has 'performance' as its main focus. By focusing specifically on the 'impact', the blue cluster offers a specialized lens through which researchers can delve into the complexities of 'job' and 'management' in a technologically mediated environment.

- The red cluster revolves around the primary effects exerted by the topic on various dimensions, including the physical 'home' environment, 'behavioral' patterns, and overarching consequences. This cluster intricately explores the dynamic interplay that arises as a result of the topic's influence on temporal 'behavior', 'energy', 'emissions', and 'health' impacts. It delves into the nuanced relationships and complex effects unfolding within the realms of the home, behavioral dynamics, and the broader implications of the subject's influence on 'time', 'covid-19', and 'air-quality'.

- Green cluster constitutes a significant domain of scientific and academic exploration, focusing on the phenomena of 'transport', 'land-use' and 'travel behavior'.

- In the purple cluster, all those aspects relevant to organizational and individual dynamics are encompassed, such as 'job demands' and 'resources'. They represent various factors that influence the work environment, employee well-being, and organizational outcomes.

- Finally, the orange cluster is devoted to a thorough analysis of the dynamics associated with the concept of design, interpreting this notion in a broad context that encompasses aspects of design and creation, planning and organization, functionality, and a strategic approach.

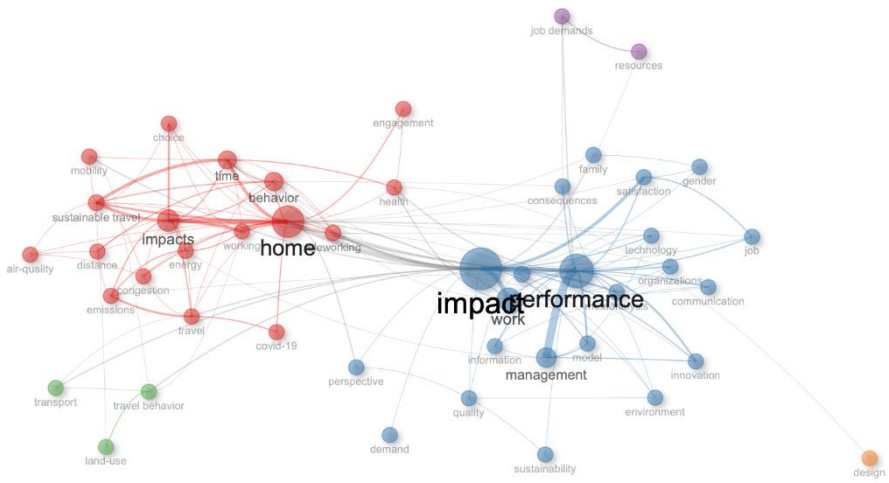

Fig. 9. Co-Occurence Network.

Figure 10 shows a thematic map, developed using the titles of the papers analyzed.

Thematic maps are useful where each research theme is characterized by two parameters: density and centrality; can therefore be classified into four sub-groups by quadrant (Cobo et al., 2011). Density is the proportion of present edges from all possible edges in the network; centrality help to identify the most important vertices in a network and the propensity of two vertices that are connected to be both connected to a third vertex. The four quadrants are:

- The top right section is themes that drive the research strand (so-called motor themes). They have strong centrality and high density. This includes ‘context’, ‘workplace’, ‘arrangements’, ‘consequences’, ‘engagement’ and ‘resources’.
- The bottom right section contains the recurring or basic themes. We found that ‘impact’, ‘performance’, ‘home’, ‘challenges’, ‘barriers’ and ‘drivers’ were all in this quadrant.
- The bottom left section is themes that may be emerging or declining, such as ‘recovery’.
- The top left section is niche themes, which are either less explored, or highly developed but isolated themes.

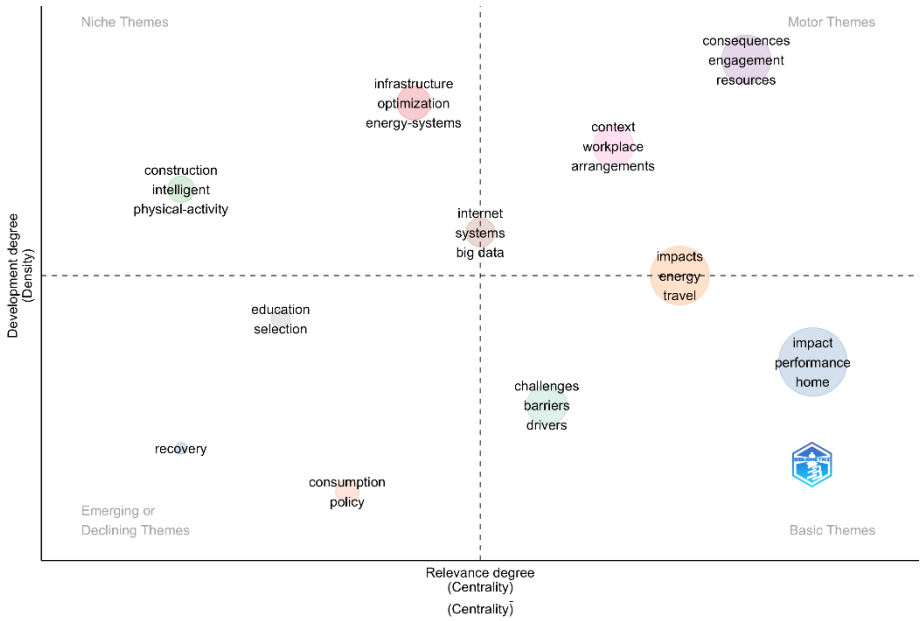

Fig. 10. Thematic Map.

Conclusion and Recommendations

The concept of remote working has evolved over time and become a topic of particular interest in last years. It now has increasing relevance for both managers in public administrations and companies, and academics. We used a bibliometric analysis to identify the most productive and influential publications and authors, and leading articles about our field. We also reviewed selected publications qualitatively to better understand the quantitative results and most popular research topics. Based on our findings, the existing studies provide significant perspectives on how smart work fosters energy efficiency and sustainability, especially within smart building frameworks and energy management systems. The strategic planning and fine-tuning of energy system controls, coupled with advancements in intelligent HVAC systems and comprehensive life cycle impact assessments, highlight the considerable potential of smart work methodologies in advancing both energy efficiency and environmental sustainability. More,specifically,.The results derived from this analysis are the following. Firstly, there's a pressing necessity for future research to prioritize measuring and quantifying the energy savings associated with remote work. Understanding the direct impact of remote work on energy consumption at both individual and organizational levels is crucial. Secondly, further exploration is warranted to identify and capitalize on opportunities for enhancing the energy efficiency of remote working. This could involve investigating the efficacy of more energy-efficient technologies or promoting sustainable behaviors among employees engaged in remote working. Lastly, it's imperative for research endeavors to acknowledge the diverse business landscapes and sectors. Uniform conclusions cannot be universally applied across all companies due to the varying nature of sectors and activities. Therefore, research should accommodate these differences to better comprehend the impact of remote working on energy consumption within distinct business realities.

Articles contribute to the literature in several ways. First, researchers and practitioners may use our findings to identify the most influential papers, academic institutions and research centers in the field. It may also help academic researchers to expand their understanding of what is happening in these fields. The study could encourage governments and companies to consider virtual teams as a solution to work issues. However, the study also had some limitations, some of which could provide the basis for future research. Future studies may explore, for example, the evolution of virtual teams outside a pandemic scenario. Another limitation of our study is that we based our research on a single database. Other researchers may use alternative academic databases such as Scopus and Google Scholar. Studies may also compare the outcomes from other databases to those proposed by our study. This field of research is at an early stage, and this study therefore provides a first exploratory step to guide future phases of research.

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ETHICAL ISSUES IN GLOBAL OIL PRICING AND ITS IMPACT ON EXCHANGE RATES AND STOCK MARKETS UNDER UNCERTAINTY

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ABSTRACT

Oil is a finite resource which have impact on global economy. Countries with abundant reserves of oil play an important role in economic wellbeing of various nations. Though relationship of oil prices with economic indicators like exchange rates and stock markets is highly complex there exist dynamic relationship between oil prices, exchange rates and stock markets. Apart from economic relationship that, oil price, has with exchange rates and stock markets under uncertainty it has far reaching consequences on ethical issues. Ethical considerations demand switching over to sustainable energy resources and to leave dependence on oil. One of the most significant ethical dilemma in the economics of oil price is the environmental impact of oil production and consumption. The burning of fossil fuels including oil contributes to problem like greenhouse emission, climate change and environmental degradation.

Oil being concentrated in countries with political instability, leads to geopolitical tension. The pursuit of oil resources lead to unethical issues like military intervention, human right abuses and support for authoritarian regime leading to universal conflict. As far as economic equity is concerned, fluctuation in oil prices hampers growth and development of nations. Higher oil prices give rise to inflation for oil importing countries. On the other hand, when oil prices drop, oil exporting countries loose revenue and face problem of providing social service. Ethical consideration demands that economist and policy makers prioritize sustainable energy resources and transition away from oil dependence.

Oil price change can affect the value of national currencies and stock market. Traders speculate on prices which lead to market volatility. Ethical issues in this area need to outweigh market manipulation, insider trading and other unethical practices.

The present paper shall highlight on the ethical issues emerging from global oil pricing and its impact on exchange rates and stock markets under uncertainty. Entire research work shall be presented in following section.

Section I shall comprise of brief introduction on need of ethical practices on global oil pricing.

Section II shall deal with impact of oil prices on Exchange Rates.

Section III shall elaborate on relationship of oil prices with stock markets

Section IV shall spell out the linkage of oil prices with Exchange Rates and Stock Markets under uncertainty

Section V shall conclude with ethical dimension of oil pricing.

Key words-Ethics, Oil Price, Exchange Rates, Stock Markets, Uncertainty

The oil price is critical in global economy.The oil production and consumption leads to environmental degradation. So it has got ethical dimension.Though oil price has dynamic relationship with exchange rates and stock markets,still it brings out several ethical issues which needs consideration.The present paper shall highlight on the ethical issues emerging from global oil pricing and its impact on exchange rates and stock markets under uncertainty. F

Section I

Need of ethical practices on global oil pricing- Global oil industry plays a critical role in world economy.It influences everything from transportation cost to price of goods and services. Ethical practices in global oil pricing is significant due to undermentioned reasons.

a) Economic Environmental Challenges- Global oil price have profound impact on world economy. Unethical practices like price manipulation and collusion among oil producing nations bring in economic instability.Fair pricing brings in economic well being among nations dependent on oil.

b) Elimination of unfair competition -Ethical practices in oil pricing lead to elimination of monopolistic competition and ensure level playing field for all participants.Unfair competition is controlled.

c) Consumer's confidence - Ethical practices in oil pricing induce customers to repose trust on industry. Transparency in global oil pricing encourages customers to build confidence on industry

d) Avoidance of geopolitical tension -Fair pricing policy based on ethical consideration reduce supply disruption and geopolitical tension related to oil.It will have far reaching consequences on both developed and developing countries.

e) Alternative energy sources - Ethical pricing mechanism internalize the cost of environmental degradation which induces to search for alternative energy sources.

f) Abiding international regulation -Ethical pricing ensures complying the local and international regulation thereby reduces market manipulation and anti competitive behaviour.

g) Fulfilling social responsibility norm -Oil industry has to meet the social responsibility norm.Ethical pricing ensures well being of communities and leads to all round ethical conduct of business.

h) Investor's loyalty -Ethical pricing builds up investors confidence.Investment will be channelized into those industry which pursue ethical pricing as it involves reduction of legal and reputation challenges.

i) Long term stability - Ethical pricing leads to long-term sustainability of oil industry.Considering the social ,economic and environmental impact on oil pricing brings in viability of oil industry.

j) International understanding - Ethical pricing builds up understanding between oil producing countries and oil consuming countries leading to international understanding

Section II

Impact of oil prices on exchange rates - The relationship between oil prices and exchange rates is complex.Impact of oil prices on exchange rates can be understood from the following factors.

a) Effect on Current Account Balance - In times of rising prices,Oil exporting countries current account balance is strengthened. The increasing demand for their currency leads to appreciation of it.

b) Central Bank's policy response to inflation- Higher oil price leads to inflation due to increase in production cost in oil importing countries. To control inflation central bank increases interest rate in those countries which influences exchange rates.

c) Economic growth prospect and impact on consumer spending - Rising oil prices increase production cost of oil importing nation and thereby retards economic growth. It also decreases consumer spending power. Oil importing nation face depreciation in currency rate due to large trade deficit.

d) Impact on currency rates - Oil price movement impacts investor sentiment and risk appetite.Rising oil prices favors oil exporting countries in terms of strengthening their currency.But uncertainties in oil prices impact currency negatively.

e) Change in Central Bank policies and government's responses -Central bank modify interest rate in situation of changing oil prices.Government adapts fiscal policy to changing oil prices.As a result the impact is felt on currency rates.

f) Global Economic environment - Downturn in global economic condition lead to low oil prices which eventually impact exchange rates.

Section III

Relationship of oil price with stock market - The relationship of oil price with stock market is also complex.It is dependent on underlying reason for oil price movement,economic environment and market sentiment.Following key factors explain the relationship of oil price with stock markets.

a) Impact on energy sector stocks - When oil price rises, oil sector companies earnings increases. It has direct impact on energy sector stocks which ultimately is reflected in stock market indices.

b) Central Bank's policy response to inflation - Rising oil prices induce inflation which necessitate increase in interest rates by Central bank.Higher interest rate affects adversely stock markets.

c) Impact on corporate earnings -Higher oil prices leads to increase in cost of energy for consumers.This leads to decrease in disposable income of consumers which ultimately reduces consumer spending.It has negative impact on corporate earnings and also affect stock market performance

d) Global Economic Growth prospects - Overall health of global economy have a bearing on stock market.Rising oil prices is a sign of increased demand which signify economic growth.It eventually result in higher stock market performance.

e) Geopolitical conflicts -Geopolitical tension and conflicts in oil producing countries induces rise in oil price which brings volatility in stock market.

Section IV

Linkage of oil price with exchange rates and stock markets under uncertainty - Geopolitical uncertainty have adverse impact on the linkage of oil prices with exchange rates and stock markets.We can study the linkage of oil price with exchange rates under uncertainty and linkage of oil price with stock markets under uncertainty separately.

a) Oil price and exchange rates under uncertainty

(i) Switching over to safe haven assets - Investors seek safe haven assets such as dollar during the time of geopolitical uncertainty. It ultimately leads to inverse relationship between oil prices and US dollar exchange rate.During rising uncertainty,investors switch over to buy US dollar which depresses oil price.On the contrary when US dollar weakens,oil prices rise.

(ii) Risk aversion - Uncertainty increases market volatility.Investors become risk avert-er. This leads to fluctuating exchange rates.

(iii) Weaker exchange rates - For oil exporting countries relationship of oil price and exchange rates are distinct. Economic uncertainty and falling oil prices lead to weaker exchange rates for commodity exporting countries as they experience trade imbalances and capital outflows.

(iv) Central Bank's Policy response - During uncertainty,Central bank adjust monetary policy to mitigate the impact on exchange rates.Central bank in an oil exporting countries, during falling oil prices may intervene in currency market and adjust interest rate to stabilize exchange rates.

(b) Oil price and stock market under uncertainty

(i) Questions future economic growth -Uncertainty lowers investor confidence and raise concerns about future economic growth. Falling oil price may be an indicator of reduced demand which leads to decline in energy stock prices.

(ii)Monetary policy of central bank to mitigate inflationary concern -Rising oil prices leads to inflation.To mitigate the inflationary effect central bank pursue tighter monetary policy which may impact stock market performance.

(iii) Effects on different sectors of stock market -The impact of oil price uncertainty on the stock market vary depending on the composition of stock market. Energy company benefit from oil price rise whereas transportation and manufacturing company witness increased cost.This result in divergent performance among different sectors within the stock market.s

(iv) Impact on economic stability - Major fluctuation in oil price lead to economic instability.Depending upon investors perception,stock market volatility may occur resulting in economic instability.

(v) Diversification of investment - Investors and companies may use hedging instrument against oil price fluctuation. Diversification among asset class will enable investors to cope with uncertainty in oil prices.

In times of high uncertainty investors should be well informed and take steps to diversify their investment portfolio.Rational investment strategy shall mitigate the negative effects of oil price uncertainty in the stock markets.

Section V

Ethical dimension of oil pricing - Several ethical dimensions are involved in oil industry.The way oil is produced and consumed have got moral and social implication.Following points clarify ethical dimension in oil pricing.

(a) Environmental degradation - First and foremost issues that concern ethical dilemma of oil pricing is environmental impact of oil industry.Oil production and oil consumption leads to green house gas emission,climate change and environmental degradation.Ethical issues arise as to the responsibility of oil companies,government and consumer in addressing the adverse consequences.

(b) Depletion of oil - Oil is a finite resource.Continuous extraction of oil shall deplete the resources for future generation.Inter-generational equity is hampered as today's consumption shall deprive the future generation to use it.

Resolving geopolitical tension - Oil pricing can be a source of geopolitical conflict.Ethical consideration requires to resolve such conflict and to address other unethical practices like human right abuse and violence.

(c) Equitable distribution of wealth - The price of oil impact both oil producing and oil consuming countries.Ethical consideration imply equitable distribution of wealth among both oil exporting and oil importing countries.

(d) Bringing social equity - The burden of high oil price is borne by vulnerable population who spend most of the income on energy consumption.Ethical issues demand fair pricing of oil for low income individual and communities.

(e) Corporate social responsibility -Oil companies have obligation of social responsibility.Ethical questions to be addressed by oil companies are related to safety,environmental protection,labour right.They are also required to be transparent in dealing with government and communities.

(f) Alternative energy sources - Ethical consideration presupposes transition to sustainable energy sources.There should be efforts to reduce use of fossil fuel and emphasis should be given for renewable energy sources.

Addressing these ethical issues for oil companies require a multifaceted approach.There should be a concerted efforts among oil companies,government,consumers and international agencies to resolve ethical dilemma.Following strategy shall be helpful for resolving ethical issues in global oil pricing and its impact on exchange rates and stock markets under uncertainty.

- Adoption of effective policy for removing environmental degradation
- Encouragement of transparent oil pricing among oil producing nations.
-.Pursuing efforts to switch over to sustainable and renewable energy sources.
- Implementation of policy for equitable distribution of wealth.
- Promoting awareness among consumers regarding energy consumption.

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DEVELOPMENTS IN OFF-GRID ON-BOARD PORTABLE ELECTRIC VEHICLE CHARGING STATION

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ABSTRACT

While the use of Electric Vehicles (EVs) is increasing rapidly, there is a need to establish many charging stations to meet this demand. Fixed charging stations (FCS), like traditional gas stations, are very difficult to install in many places in terms of both cost and technical infrastructure. Lack of available FCSs, range anxiety and too long overall charging time are seen as major obstacles to the widespread adoption of EVs. Charging stations will have difficulty in meeting the charging needs demanded in all locations due to infrastructure deficiencies and various electrical problems that will occur in existing electricity distribution systems. Thus, the pace of development of EVs in the market will slow down. At this point, Mobile Charging Stations (MCS) can be considered as a solution to compensate for the difficulties mentioned and to increase the demand of EVs in the automobile industry. The idea of meeting the charging needs of EV users in emergency situations constitutes the basic function of MCSs. In this publication, it provides technical information about the benefits of MCS in the systems it is connected to, connection difficulties, and ways of using it, while also stating that it creates a flexible time and location charging opportunity to support FCSs. The costs that users will pay and the technical information they need to know when benefiting from MCS services, as well as the effects of this charging system on the existing distribution network, have been examined and suggestions have been presented.

Keywords: Electric Vehicle, Mobile Charging Station, Charging Infrastructure, Off-grid Charging

INTRODUCTİON

The increase in world population, technological developments and environmental concerns force the energy sector to make major changes. One of these important changes is how EVs will be electrified in the transportation sector. It is estimated that by 2030, more than 110 million EVs will be on the road worldwide and these EVs will demand a total power of approximately 500 TWh. Additionally, it is predicted that the energy demand of the transportation sector will reach 11% of global demand by 2040 (Cozzi et al., 2020). The spread of decentralized energy systems and the increase in the number of consumers producing their own electricity reveal the necessity of advanced management systems in electrical power systems. Considering the increase in the diversity of instruments in the system, it will not be sufficient to meet this demand by establishing more centralized power plants. At this point, there is a need to optimally manage such a large system, bidirectional energy flows and load demand of EV charging stations using information technologies (Alsharif et al., 2020). In off-grid systems, many consumers want to have electricity generation equipment and equipment to charge their EVs and use them if distribution companies allow it. In addition, they may want to store the energy produced from different sources, use this stored energy during the time period when there is the highest demand, or gain economic profit by selling it. At this point, private companies and electricity distribution companies develop their own solutions and offer Mobile Charging Stations (MCS) to consumers in a safer, faster and more reliable way in order to respond to energy demand (Taik et al., 2021). Due to their popularity, most of the studies available in the literature are related to FCSs. Apart from the products produced by the relevant EV manufacturers themselves, there is detailed information about the technology of MCSs in the literature.

- MCS is mentioned as a new class of EV charging methods. There is no study in the literature that includes MCS with different charging technologies.
- Knowledge of mobile charging technologies is demonstrated both in application and in terms of research aspects. It includes information such as the development level, structure, benefits, planning, operation and market status of MCSs.
- The status of MCSs is evaluated on issues such as charging time, range anxiety and charging availability. Additionally, the effects of mobile charging technologies on FCSs and the electricity grid were examined.
- Opportunities, difficulties and lack of information about MCSs were mentioned. MCSs are mentioned in terms of their benefits, planning, application methods and effects on the network.

RESEARCH AND FINDINGS

Today, along with the developments in FCSs, progress has been made in MCSs, and an increase in their number has been observed in America, China and European countries (Shaohua et al., 2020). Nation-E company introduced the world's first MCS prototype in 2010. The main purpose of MCS was to provide charging service for EVs for rescue purposes in emergency situations when the vehicle battery is dead. High-capacity MCSs have now begun to be preferred as much as FCSs. (Yaoli et al., 2020). Figure 1 shows the classification scheme of different technologies that will meet the charging needs of EVs (Afshar et al., 2021).

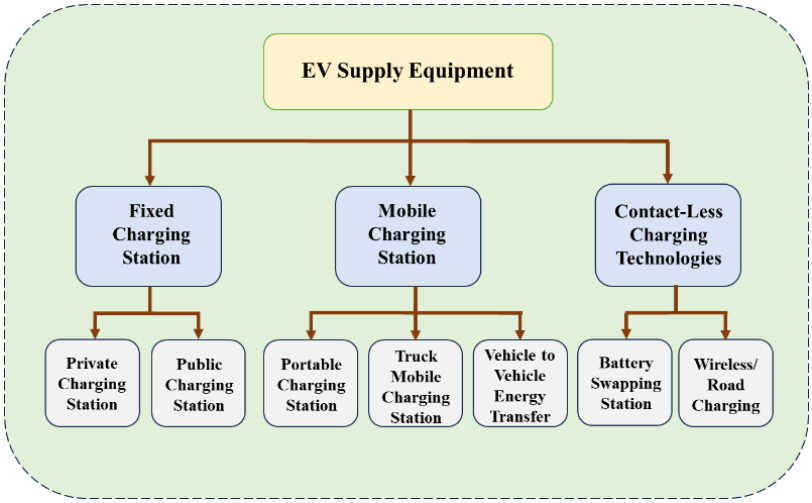

Figure 1. Classification of Charging Methods

MCSs are a new type of electric vehicle charging equipment that has the necessary equipment for the charging services that EVs need at any place or time period. MCSs were developed in response to overcharging demands when both EVs and FCSs were insufficient (Cui et al., 2018). Due to the increasing interest with the developments in MCS technology, the unknown aspects of this technology will be mentioned in this article.

A- Technologies and Types

Just as there are many types of EVs, several types of MCSs are included in the literature. MCSs are categorized as truck mobile charging stations, portable charging stations and vehicle-to-vehicle power transfer. (Dwi & Midriem, 2015). Truck mobile charging stations (TMCSs) are truck or pickup type hybrid or electric vehicles with many charging outputs to meet the charging needs of EVs at a certain distance. TMCSs are of four types: battery-integrated type, battery-less type, robot-like type and battery-swapping type, as shown in Figure 2 (Yong, 2019).

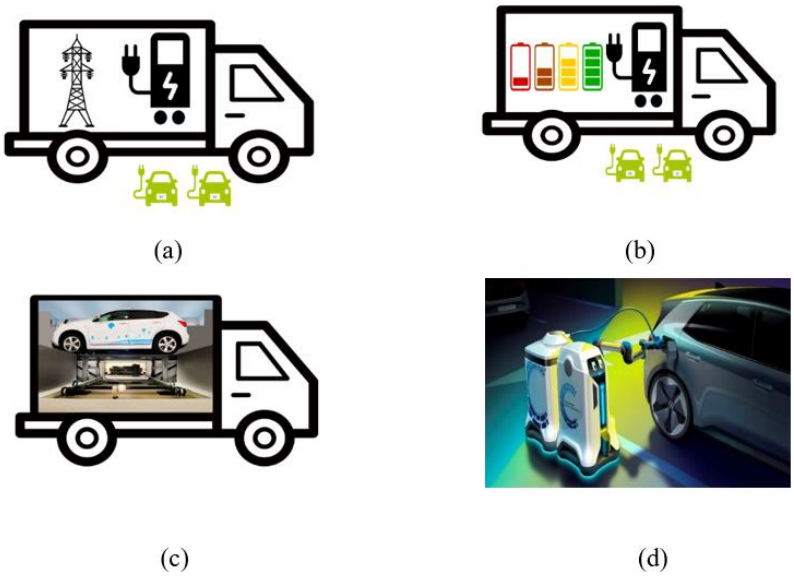

Figure 2. Truck mobile charging stations: (a) Battery-less TMCS, (b) Battery-integrated TMCS, Mobile battery-swapping stations. (c), (d) Robot-like mobile chargers

Portable charging stations include a mobile energy storage system mounted on some types of truck MCSs and towed by a vehicle. These high-capacity stations can also work temporarily in other events where high EV charging needs are required (Fred, 2019). Energy exchange between two identical EVs is described as vehicle to vehicle (V2V) power transfer. One of them works as an EV energy receiver and the other as an energy transmitter. Since many EV users only drive their vehicles 40-50 kilometers each day, it is possible to use their remaining charge from V2V. It is possible to use EV batteries as energy storage elements in long-term parking situations. Since EVs that have the ability to transfer energy from V2V are generally used for transportation, this causes difficulties in using them to transfer energy. (Aashish & Eyuphan, 2020).

B- Structure of MCS

Structure of the battery-integrated TMCS is shown in Figure 3. As seen in the figure, this structure has an AC charger input and two types of charger outputs for DC and AC charging at different charge levels. If we want to use trickle charging, we must use the AC charger output where the DC/AC inverter is located. If we want to get DC charging output, we must use the DC charging output with a DC/DC converter. You can use the AC charging port to benefit from the electrical grid and charge your batteries. It is also equipped with a battery management system that monitors the status of the ESS and controls the charger system. The last part includes the measurement and billing system that performs the charging and transfers the prices to the users. Other energy storage technologies such as ultracapacitors and fuel cells are also found in new applications of MCSs (Daniel et al., 2019).

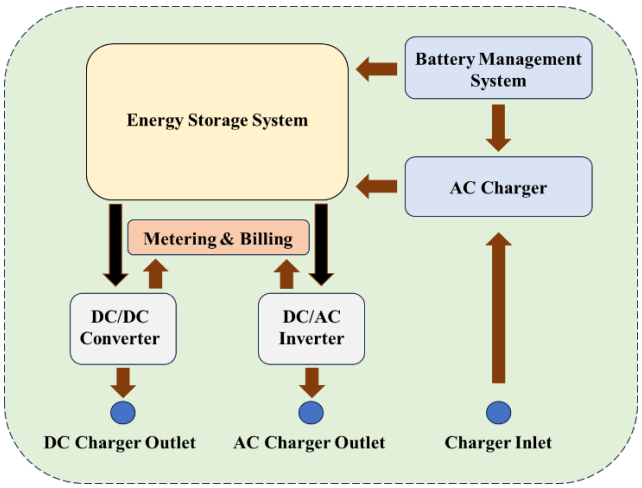

Figure 3. Structure of battery-integrated TMCSs

C- Benefits of MCS

MCSs address various shortcomings of FCSs to improve the EV driving experience. Moreover, reducing the negative impacts of FCSs on the electricity grid and motivating investors to invest in FCSs are other beneficial effects of MCSs (Shabab et al., 2020). Figure 4 shows a summary of the benefits of MCS.

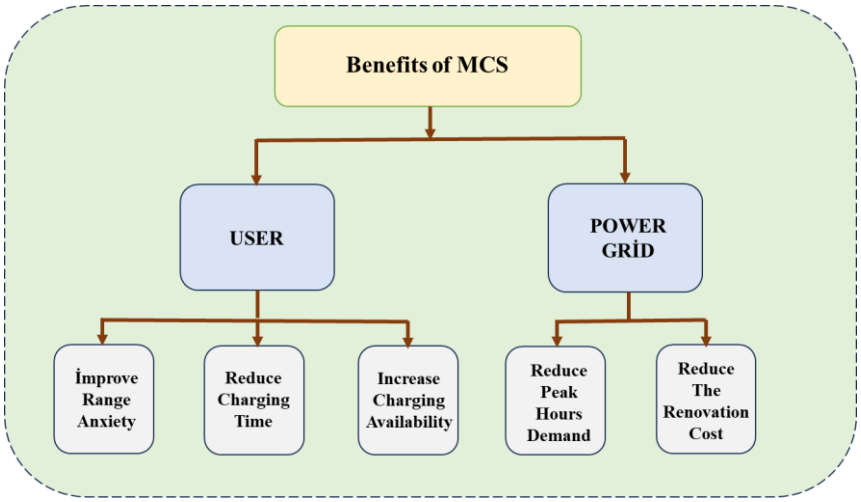

Figure 4. Benefits of MCS

When we look at it from the perspective of EV users, as it is known, the difficulties experienced by EVs in traveling long distances are cited as range anxiety in the sector. In order to solve the range problem, the number of FCSs that EVs can easily reach should be increased and spread to all points of the region. When such an application is made, it brings about large investment costs. At this point, it offers a solution to decrease the range anxiety of EV users by supplying them with additional equipment with MCSs and causes the infrastructure investments to be made in FCSs to be less (Goro, 2019). The mass use of EVs causes a serious problem regarding the rechargeability of EVs. Firstly, the limited number of charging outlets of FCSs during periods of sudden high charging demands causes them to have difficulties in responding to the demand. Secondly, due to the large number of hybrid vehicles, the density of EVs will increase and in this case, situations such as EVs not being able to be charged or having to wait for charging for a long time will arise. Thirdly, EVs generally charge in the car parks of their homes, but since most homes do not have their own car parks to charge, this causes congestion at public charging points (Rotthier et al, 2013). The total charging time of an EV includes the arrival time at the charging station, waiting time in the queue, charging time and return time. In general, the time required for hybrid vehicles to fill their tanks at gas stations is much faster than the charging time of an EV user. The only competitive charging technology is Fast Charging (FC) with

rechargeable DC, which can power an EV up to 80% chargeable in about half an hour. However, only 16% of currently existing public charging stations have a FC system with DC. When we include the travel time on the way to FCSs and the processes we wait in the queue for charging there, the solution to this situation is that the charging capacities that MCSs provide to EV users at their request and wherever they want save more time (Valeh et al., 2021). From a grid perspective, with the increase in EV usage, the amount of energy demanded will increase. The demand for EV charging during the network's peak period causes both high charging prices and various technical difficulties on the network. The faster the charging process, the more negative its effects on the electrical grid can be (Kaya, 2023). For example, the amount of energy consumed by the homes of 140 families is the amount of energy of an EV that performs a 10-minute fast charge. Moreover, large-scale AC level-1 charging or AC level-2 charging in residential districts significantly rises electricity utilization and causes detrimental effects on the existing distribution network. The increase in AC level 1 charging or AC level 2 charging significantly increases the electrical energy drawn from the grid and strains the distribution grid in many ways. From this perspective, MCSs can also be considered as a solution to these negative situations of the network (Bo et al., 2016)

D- Challenges of MCS

Designing it by taking into account the technical limitations inherent in the MCS, monetary costs and the expected life of the batteries are some of these difficulties. In addition, designing power electronic elements such as converters, energy transfer outfitting and control system is of vital importance for MCSs (Xiaolin et al., 2019). During planning, determining the optimal number and location of the MCS's charging depots, determining the MCS's fleet size and battery size should be taken into account (Peng et al., 2020). In terms of operation, MCSs will face two main challenges, namely balancing supply and demand and maximizing power transfer efficiency to ensure optimal energy utilization. Considering the probabilistic and dynamic behaviour of charging demand, achieving various goals such as improving service quality, reducing operating cost are among other challenges faced. Additionally, in cases where V2V operation occurs, possible customer behaviour and customer satisfaction must be taken into account, as the supplier depends on how the EV owner behaves. Creating a charging navigation system so that MCSs can choose the most appropriate departure points for charging is an important problem (Guangyu et al.,2019).

E- Design and Planning of MCS

In terms of planning and design of MCSs, it is of great importance to find the optimum number of MCSs to meet charging demands. The cost range for a fast DC FCS is approximately $60,000, while the estimated cost of an MCO is approximately $40,000. To reduce service delay, it is important to increase the number of TMCS and optimize the charging outputs of each TMCS. Research shows that when the number of charging outlets is increased from 1 to 4, the waiting time in the queue decreases from 89 minutes to 5 minutes. Criteria such as budgets intended to be spent and range anxiety determine the location distribution, type and number of EV chargers (Shaohua et al, 2018).

F- MCS in Practice

Believing that the demand for EVs will increase in the future, automobile manufacturers are investing more in EV Technologies. Some companies, which have become important brands in different sectors, are now investing more in the production of EV charging equipment facilities. These companies include major oil and energy companies such as Shell and British Petroleum Company and engineering companies such as Siemens. However, some companies go further and offer new services, including MCS, which provides charging services for electric vehicles (Francis, 2019). Table 1 shows the companies operating in MCS hardware and the technologies they use for their products.

Table 1. MCS ownership and technology.

Scope of Activities	Company Name	Technology	
		TMCS	PMCS
EVSE Companies	Andromedapower	x(Truck)	x
	Berlin's Chargery		x
	EV Safe Charge		x
	ChargeWheel	x(Van)	
	Freewire		x
	Lightning Mobile		x
Other Companies	AAA	x(Truck)	
	British Petroleum		x
	Nation-E AG	x(Van)	
Automaker	NIO	x(Van)	
	Tesla	x(Truck/Triler)	
	Volkswagen		x

In 2010, Swiss energy storage company Nation-E AG introduced a world-first TMCSs to help electric vehicles continue their journey to a nearby charging station. In terms of providing mobile charging services, Volkswagen and NIO are two automakers that have adopted MCS as a new charging service for charging EVs. Tesla also recently made its first mobile supercharging station. Some independent companies also serve as either fixed charging service providers or mobile service providers. Table 2 shows the companies producing each MCM and their charger information (Lambert, 2019).

Table 2. MCS Characteristics.

Company Name	Charger Information			
	ESS Capacity (kWh)	FC Ability	Charging Speed (kW)	Main Purpose
Andromeda	25	CCS & CHAdeMO	50	Rescue Services
ChargeWheel	550	DC FC	No Data	Normal / Rescue Services
NIO	270	DC FC	No Data	Rescue Services
Freewire	80	DC FC	120	Rescue Services
Tesla	3000	Tesla Charger	125	Normal Charge
Lightning Systems	192	DC FC	80	Rescue Services
Volkswagen	360	CCS Combo	100	Normal Charge
Berlin's Chargery	24	In Progress	3,7	Rescue Services
Volkswagen (Robot-Like)	25	CCS Combo	50	Normal Charge
EV Safe Charge	No Data	DC FC	50	Rescue Services

CONCLUSIONS

This study also discussed different research ways such as benefits, challenges, planning, technologies and types of MCS to EV users and power grids. It was concluded that MCS will increase day by day and more research is needed on problems or improvements related to this field. These research areas include optimal coordination between different charging methods, including MCS, reducing the negative effects of high EV usage on electricity networks through MCS, and the effects of MCS on the EV market. This publication serves as a step towards understanding the state-of-the-art in the field of EVs and a guide for new approaches to make EV charging of MCSs as easy and fast as refuelling in gasoline vehicles.

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DATA-BASED MODELS FOR REMAINING USEFUL LIFE ESTIMATION OF TURBOFAN ENGINES -A REVIEW

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ABSTRACT

The most vital component of effective maintenance planning for turbofan engines is the estimation of the remaining useful life (RUL) of the engine. Physics-based models for RUL prediction require expertise in domain knowledge and even with expertise it is exceedingly difficult to construct the equations that represent the degradation process of the engine. With the advancements in the sensor technology, various parts of the engine's health could be monitored providing a lot of data. Therefore, data-based models for RUL prediction gain importance. The data-based models especially deep learning-based models have attracted a lot of attention. In this study, we reviewed the literature on deep learning-based models for RUL prediction of turbofan engines.

Keywords: Turbofan Engine, Remaining Useful Life, Deep Learning.

PREDICTIVE MAINTENANCE

It is a type of maintenance in which the system is tried to be evaluated by periodically or continuously monitoring the system. Predictive maintenance is the determination of the maintenance and repair features of the equipment through observations made through special devices in the system, special inspection devices, and record monitoring systems, and the realization of these parts at the appropriate planned times. Predictive maintenance monitors each employee's energy to detect malfunctions and ensures unplanned stoppages and reductions in malfunctions. The features of special measuring devices are monitored, and the operating data of the equipment is stored. The resulting measurement data is measured at certain time intervals. By comparing the operating conditions of the equipment with the desired conditions, it is determined whether there is a problem in the system or whether a problem will arise. The data received from the equipment analyses the intervals of the intervals. Since the predictive maintenance system makes operational evaluations, unnecessary downtime of the facilities is prevented. In short, with this method, the components of a working system are monitored, and data is received. Obtains information about the lifespan of the details of the received data. While monitoring equipment, data such as pressure analyses, pressure, power, humidity, and temperature are taken into consideration. Changes in the data and trends in the data are evaluated. A planned maintenance is prepared in the light of this data. It is especially important to benefit from technology as much as possible during predictive maintenance to prevent malfunctions that may occur in the system before they occur. The most important feature that distinguishes predictive maintenance from other types of planned maintenance is that maintenance is conducted based on the current state of the machine rather than a predetermined program. [Gulati, 2009], [Palmer, 2013], [Campbell, 2015].

MAINTENANCE PLANNING

In predictive maintenance, optimizing maintenance planning is especially important for the efficient operation of turbofan engines and the long life of internal equipment. Using real-time data and condition monitoring, maintenance schedules are optimally tailored to the engine's condition.

Optimization Techniques

Various optimization techniques used in maintenance planning are as follows;

Condition Based Maintenance (CBM)

CBM is used to monitor the condition of the engine in real-time and perform maintenance when certain threshold conditions occur. This maintenance method ensures that maintenance is conducted by targeting the optimal use of resources [Millar, 2008].

Reliability Cantered Maintenance (RCM)

RCM works on the overall reliability of the system and is the approach that identifies the most critical situations and maintenance tasks. It prioritizes maintenance by focusing on critical situations and helps make the maintenance plan optimal [Millar, 2008].

Prognostics and Health Management (PHM)

PHM combines real-time data with predictive statistical methods to estimate the RUL of engine components. It detects malfunctions with forecasting methods and makes plans to reduce downtime, increase equipment efficiency, and reduce maintenance costs [Millar, 2008].

EVALUATION METRICS

Root Mean Square Error (RMSE)

RMSE aids in model selection by measuring the average magnitude of the difference between predicted and actual remaining useful life values. The lowest RMSE value indicates better model performance [Chicco D, 2021].

Mean Absolute Error (MAE)

MAE aids in model selection by measuring the average magnitude of the difference between predicted and actual residual useful life values, regardless of the direction of the difference. A lower MAE value indicates better model performance [Chicco D, 2021].

R-squared (R^2)

R-squared aids in model selection by measuring the proportion of variance in actual remaining useful life values that can be explained by predicted values. A higher R-squared value indicates better model performance [Chicco D, 2021].

LITERATURE STUDY

Khelif et al., a model is proposed to estimate remaining useful life based on support vector regression. The turbofan dataset was used to evaluate the performance of the proposed model. The authors proposed a method that can estimate the remaining useful life of equipment with the help of sensors, without the need to estimate the degradation time or degradation threshold. The relationship between sensor data and health indicators was modelled using support vector regression. It is emphasized that using this model, RUL can be predicted instantly during the degradation process before the failure occurs. They concluded that with this method, immediate intervention can be made before the failure is caused, it reduces the calculation time and increases the remaining useful life estimation accuracy [Khelif, 2016].

Liu et al., to improve the RUL prediction accuracy of the aircraft engine, proposed a new aircraft engine RUL prediction model, which they call clustered multi-stage long short-term memory network (ILSTMC). With this proposed model, an attempt was made to develop a multi-stage RUL prediction algorithm that integrates the advantages of cluster analysis and the LSTM model. As a result of the experimental studies, they observed that the proposed method significantly reduces the aircraft engine RUL prediction error. The National Aeronautics and Space Administration (NASA) dataset was adopted for validation [Liu, 2021].

Li et al., propose a method to estimate the remaining useful life of aircraft modules with the module obtained by modelling information and deep learning models. A knowledge-driven hybrid model (KGHM) is proposed, combining the proposed module knowledge and deep learning models. The proposed approach transformed sensor relationships as embedding vectors for clustering and represented them as flowcharts. These clustering results were then used to guide sensor data manipulation and hybrid deep learning model construction. As a result of the study, they concluded that the proposed approach improved the prediction by 5.5% compared to their literature study. In their research, it was emphasized that combining knowledge and deep learning models for prediction results could be applicable and interpretable [Li, 2023].

Nieto et al. proposed a hybrid model for remaining useful life (RUL) prediction for aircraft engines using a hybrid PSO–SVM-based method. The proposed hybrid model combined support vector machines (SVMs) with particle swarm optimization (PSO) techniques for regression problems. They emphasized that one of the most important advantages of this method is that it does not require information about the previous operating states of the engine. As a result of the study, the regression accuracy of the proposed hybrid system was found to be approximately 95% [Nieto, 2015].

Ma et al., propose a new deep neural network, which they call convolution-based long short-term memory (CLSTM), to accurately predict the remaining useful life of rotating machines. They emphasized that there are many studies in the literature where a convolution-based neural network (CNN) is connected to a long short-term memory (LSTM) network. They emphasized that their proposed system, unlike those found in the literature, conducts convolutional processing on both input-to-state and state-to-state transitions. They created a coding-prediction architecture with the proposed system and created a deep-learning model for RUL prediction. Operational tests were conducted until the bearings failed and vibration responses were collected. RUL was estimated using the proposed module, and as a comparison, the performance of other methods, including deep CNNs and deep LSTM, was evaluated using the common dataset. Thus, they achieved better prediction accuracy and calculation efficiency as a result of comparisons of the CLSTM network [Ma, 2020].

Costa et al. proposed a new approach based on variational coding in which monitoring data is evaluated to estimate the remaining useful life of an aircraft engine. The model they created is a recurrent encoder and a regression model. The encoder created the input data into a self-explanatory map that can visually evaluate the rate of degradation of aircraft engines. Data from turbofan engines were used in this study. They supported their Remaining Useful Life (RUL) prediction comments with the data they obtained. They emphasized that thus, not only an interpretation-based evaluation but also a prognostic accuracy can be achieved [Costa, 2022].

Wang et al., propose a physics-supported long-short-term memory network based on the change of time-frequency data to predict the remaining useful life of bearings in the process of degradation. It is emphasized that a physics-supported memory network is used to ensure that the proposed long-short-term memory network complies with the real laws of physics and to make a more realistic remaining useful life estimate. By dividing the proposed system bearing degradation stage into a healthy state and a deteriorated state, noise model results in the bearing vibration signal were obtained. Then, dynamic weights were selected to ensure physical consistency such as Pearson correlation coefficient and robustness. As a result of the study, the physics-supported memory network created was compared with experimental data and it was stated that a consistent remaining useful life estimate was made [Wang, 2024].

Xiang et al. they developed a mass-conserved long- and short-term memory network (MCLSTM)-based framework to more accurately and robustly predict the remaining useful life of aircraft engines. MCLSTEM is composed of level division units and multi-cell units in the hidden layer. They designed a level division unit to determine the importance of input data so that different data can represent different trend information. The existing input data was divided into five levels: high, medium-high, medium, medium-low, and low, with the help of the proposed new unit. The five levels correspond to five trends in life cycle degradation. They designed different update modes in multi-cell units depending on the levels of data obtained. By processing the data obtained from MCLSTM, information about the health status of the aircraft engine was obtained. From the

experimental results, they concluded that the proposed methodology is far superior to existing remaining useful life estimation approaches [Xiang, 2021].

Hu et al. created an automatically extendable cascaded long-short-term memory (ACLSTM) model for the remaining useful life estimation of aero-turbofan aircraft engines. The ACLSTM model was supported by empirical formulation optimization. This proposed model has an extended cascading mechanism of submodules. It is aimed to minimize the prediction error with the help of these submodules. It was also stated in the study that prediction errors would decrease as the submodule level increased. They stated that due to the complex mechanical structure and operating state of aircraft engines, the prediction accuracy of the LSTM network alone would not be sufficient, so they proposed an automatically expandable cascaded long short-term memory (ACLSTM) prediction model, which includes the lifetime change laws of aircraft engines. The proposed ACLSTM model adopts the network structure of a plurality of LSTM modules connected stepwise to continuously adjust the previous prediction errors as the training outputs of the next module. Thus, they claimed that the original data would effectively reduce the prediction error by transforming the prediction process into an output error. They tested this proposed model against four subsets of the C-MAPSS dataset published by the National Aeronautics and Space Administration. They observed that the proposed ACLSTM prediction model reduced the root mean square error (RMSE) by an average of 95.44% compared to a standard LSTM network [Hu, 2023].

Mitici et al. developed a probabilistic RUL prognosticator using convolutional neural networks to estimate the remaining useful life of a turbofan engine. When the proposed system is compared to the traditional time-based maintenance strategy, a 53% reduction in cost is achieved [Mitici, 2023].

Lei et al. proposed a model-based method to estimate the remaining useful life of machines. The proposed method consists of two modules: indicator structure and RUL estimation. The first module includes a new health indicator called weighted minimum quantization error. This new indicator combines data containing common information from the obtained data and relates this data to the malfunction process of the machine. The second module initializes the model conditions using a probabilistic prediction algorithm and estimates the RUL using an equipment allocation-based algorithm. The authors used this two-module RUL estimation method, which they proposed, using the vibration signals obtained in the distortion tests of rolling element bearings. They concluded that the proposed method can be effectively used in the RUL estimation of machines [Lei, 2016].

Tian developed an artificial neural network (ANN)-based method to improve the remaining useful life estimation of parts based on condition monitoring. He stated that the ANN module uses age and multi-state monitoring measurement values at the current and previous control points as input data, and the percentage of life as output data. The proposed system has been validated using real vibration monitoring data collected on pump bearings. He stated that the ANN method he proposed could be applied to obtain RUL estimation [Tian, 2012].

Kang et al. tried to predict the remaining useful life of equipment in production lines by modeling artificial neural networks. In their study, they proposed a new artificial neural network model that can automatically perform equipment failure prediction. The proposed system consists of a multilayer perceptron neural network (MLP) machine learning algorithm. They used their proposed approach as a case study to estimate the RUL of engines in NASA turbofan engine datasets. They concluded that the proposed approach is effective in RUL prediction and improves predictive maintenance results [Kang, 2021].

Babu et al., proposed a deeply applied convolutional neural regression network for the prediction of remaining useful life. The network consists of two-dimensional convolution layers for feature selection followed by a regression layer for prediction. For 2D convolution, we first need to convert our 1D sensor data into 2D, the other being taken as the amplitude of the sensor. The model has been shown to increase efficiency [Babu, 2016].

Mo et al., proposed a multi-head neural network for predicting the remaining useful life of a turbofan engine. This network is different from normal neural networks. They implemented the parallel branches of the deep applied convolutional neural networks layer with the LSTM network. Fisher method with iterative least squares and single exponential correction was also used to find the prediction error and added as data to CNN-LSTM for optimum performance [Mo, 2020].

CONCLUSION

In this study, we examined studies on estimating the remaining useful life of turbofan engines.

Efforts were made to increase engine reliability and reduce downtime through predictive maintenance work.

Data analytics, machine learning, artificial neural networks, etc. Predictions were tried to be made with models.

By implementing predictive maintenance practices, we can maximize the life of turbofan engines and ensure their safe and reliable operation.

With data-driven models, the remaining useful life can be accurately predicted and generalized for different systems without requiring a domain expert.

By making maintenance plans in an optimized way, we can increase the life of the equipment and equipment components and minimize unnecessary downtime in the processes involving the equipment.

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KAMU HASTANELERİNDE ENERJİ VERİMLİLİĞİ UYGULAMALARI

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ÖZET

Nüfus artışı, ekonomik büyüme, endüstriyel üretim, iklim koşulları ve teknolojik gelişmeler gibi faktörler her geçen gün enerji tüketiminin artmasına sebep olmaktadır. Fosil yakıtların tükenebilir olması, enerji kaynaklarının sürdürülebilirliği açısından önemli bir sorundur. Bu nedenle, fosil yakıtların tükenmesi, dünya genelinde enerji politikalarının yeniden gözden geçirilmesine neden olmuştur. Ülkemizde birincil enerji kaynaklarının önemli bir miktarı ithalat yoluyla elde edilmektedir. Enerjide gerek dışa bağımlılığı azaltmak gerekse de iç kaynakları etkin kullanmak amacıyla ülkeler enerji verimliliği politikaları geliştirmekte ve uygulamaktadır. Ülkemizde enerji verimliliği politikaları ve önlemleri 2 Mayıs 2007 tarihinde yürürlüğe giren 5627 sayılı Enerji Verimliliği Kanunu'na dayanmaktadır. Bu kanunun amacı, enerjinin etkin kullanılması, israfın önlenmesi, enerji maliyetlerinin ekonomi üzerindeki yükünün hafifletilmesi ve çevrenin korunması için enerji kaynaklarının ve enerjinin kullanımında verimliliğin sağlanmasıdır.

Enerji tüketiminde önemli bir paya sahip olan kamu binalarıyla ilgili enerji verimliliği uygulamaları literatürde geniş bir şekilde yer almaktadır. Bu çalışma kapsamında, 7/24 hizmet verme esasına dayanan kamu hastanelerinde enerji verimliliği potansiyelinin yüksek olacağı öngörülerek, uygulama binası olarak bir kamu hastanesi binası seçilmiştir.

Anahtar Kelimeler: Enerji tüketimi, enerji verimliliği, kamu hastanesi.

GİRİŞ

Ülkemizde Enerji verimliliği politikaları ve önlemleri 2 Mayıs 2007 tarihinde yürürlüğe giren 5627 sayılı Enerji Verimliliği Kanunu'na dayanmaktadır. Bu kanunun amacı, enerjinin etkin kullanılması, israfının önlenmesi, enerji maliyetlerinin ekonomi üzerindeki yükünün hafifletilmesi ve çevrenin korunması için enerji kaynaklarının ve enerjinin kullanımında verimliliğin artırılmasıdır (Enerji Verimliliği Kanunu, 2007).

Nihai enerji tüketiminde binalar, Türkiye'de yaklaşık %34, dünyada ise %40 ile en büyük paya sahiptir. Bu durum, binalara yönelik enerji verimliliği çalışmalarının önemini ortaya koymaktadır (Kamu Binalarının Enerji Verimli Yenilemesine Yönelik Rehber, 2019).

Karamanoğlu Mehmetbey Üniversitesi yerleşkesinde enerjinin verimli kullanılabileceği noktalar tespit edilerek yıllık 268,5 TEP birim enerjinin tasarruf edilebileceği ve üniversite ekonomisini üzerindeki enerji maliyetinin azaltılabileceği tespit edilmiştir (Rüşen vd., 2018).

Adıyaman Eğitim Araştırma Hastanesi binası için mantolama yapılması durumunda %8 enerji tasarrufu olacağı sonucuna varılmıştır (Güvenç, 2013).

Selçuk Belediyesi binasında, maliyetsiz bir şekilde lamba sayısı yarıya düşürülerek aydınlatmada %25, kazanın hafta sonları (92 gün/yıl) çalışmasını engelleyerek yaklaşık %13, kazanlara ekonomizer takılarak %5, aydınlatma sistemindeki 56 Watt, 64 Watt floresan lambaların 35 Watt LED lambalarla değiştirilmesinin binanın aydınlatmasında yaklaşık %60 elektrik tasarrufu sağladığı belirtilmektedir (Tosun, 2018).

"Hastane İçin Güneş Enerjili Mikro Şebeke Kapasite Planlaması" adlı başka bir vaka çalışmasında, birleştirilmiş PV sisteminin optimum boyutunu kurarak bir hastanenin yıllık enerji maliyetinin %30 oranında azaltılabileceği belirtilmektedir (Chau vd., 2018).

Garuda Pavilion Dr. Kariadi RSUP Binasındaki (Endonezya) yapılan çalışmada yapay aydınlatma için başlangıç koşullarında lamba sayısı düşürülebileceği ve ortalama enerji tüketimi açısından daha verimli bir LED lamba ile değiştirilebileceği anlatılmaktadır (Nofianto Vd., 2020).

Bulgaristan'da bir hastanede yeşil bina çalışması için fotovoltaik piller ile elektrik üretiminden bahsedilmektedir. Üretilen enerji hem hastanenin kendi tüketimi için hem de fazla olan üretimin satışı için yapılan çalışmalardan bahsedilmektedir (Boychev, 2022).

Fas hastaneleri için yapılan başka bir çalışmada ise, tesislerin enerji performans göstergelerini iyileştirmeyi amaçlayan bilimsel bir yaklaşımı uygulamak ve enerji verimliliğine ilişkin karşılaştırmalı değerlendirmeye dayalı bir "iyi uygulamalar kılavuzu" geliştirmek amaçlanmıştır (Nourdine vd., 2019).

Hindistan'da yapılan çalışmada, binada kullanılan tüm elektrikli aletler Enerji Tasarrufu Bina Koduna ve Enerji Verimliliği Bürosu derecelerine dayandığı, ana odak HVAC sistemi, Su Arıtma Tesisi, Bina Yönetim Sistemi, Güneş Enerjili Su Isıtma Sistemi, Katı Atık Üretimi ve Yönetimi ve Kanalizasyon Arıtma Tesisi üzerine çalışma yapılmıştır (Singhal vd.,2019).

Tayland'da 200 yataklı bir hastanede, elektrik enerjisi izleme sisteminin enerji verimliliğini arttırabileceği ancak veri sistemlerinin hastanenin büyüklüğü sebebi ile karmaşık olduğu belirtilmiştir. Bu nedenle, hastanedeki elektrik enerjisi izleme sisteminden elde edilen büyükverilerin analiz edilmesi üzerine çözümler sunulmaktadır (Sarikprueck vd., 2017).

Hindistan'da yapılan başka bir çalışmada yapay aydınlatmanın, enerji tüketiminde önemlibir paya sahip olduğu, enerji tasarruflu aydınlatma planlanırken, aydınlatma yükünü ve enerji tüketimini sınırlarken, lüks seviyesi gereksiniminden ödün verilmemesi gerektiğinden bahsedilmektedir (Shripad vd., 2017).

Portekiz'de yürütülen sağlık sektöründe enerji verimliliği uygulamalarına ilişkin anket sonuçları sunulmaktadır. Ankete göre, çoğu durumda hastanelerde ve sağlık merkezlerinde enerji verimliliğinin iyileştirilmesine yönelik ilgi ve istek olduğu, ancak birçok tesiste enerjinin verimli kullanılmasına ilişkin günlük uygulama gerçekten rasyonel bir davranıştan uzak olduğu belirtilmektedir (Paulo vd., 2009).

Fas'ta yapılan başka bir çalışmada, hastaların ve sağlık personelinin konforunu, hizmetinsürekliliği ile hijyen ve güvenlik seviyesini korumak ve iyileştirmek amaçlanmıştır. Hedeflenen ekonomik performansı elde etmek için enerji kullanımlarını anlama ve enerji performans seviyelerinin değerlendirilmesine ilişkin bir metodoloji geliştirildiği belirtilmektedir (Nourdine vd., 2020).

Arjantin'de yapılan bir çalışmada ise, enerji verimliliği için, dışcephede daha fazla ısı kaybına sebep olan durumların tespiti için çalışmalardan bahsedilmektedir (Urteneche Vd., 2021).

ARAŞTIRMA ve BULGULAR

Enerji tüketiminde önemli bir paya sahip olan kamu binalarıyla ilgili enerji verimliliği uygulamaları literatürde geniş bir şekilde yer almaktadır. Bu çalışma kapsamında, 7/24 hizmet verme esasına dayanan kamu hastanelerinde enerji verimliliği potansiyelinin yüksek olacağı öngörülerek, uygulama binası olarak bir kamu hastanesi binası seçilmiştir. Bu hastane binasında yapılan uygulamalar sonucunda elde edilen veriler enerji verimliliği uygulamalarıyla ilgili önemli ipuçları vermektedir. Uygulama alanı olarak seçilen hastane binasında çeşitli enerji verimliliği çalışmaları gerçekleştirilmiştir.

Resim 1. Atatürk Devlet Hastanesi Uydu Görüntüsü

Tablo 1. Hastane Bina Bilgileri

Bina Bilgileri	Özellikleri
Hizmete Açılış Tarihi	**1964**
Kullanım Amacı	**Devlet Hastanesi**
Kapalı Alan	**14544 m²**
Bina Oturum Alanı	**4915 m²**
Kullanım Alanı	**40.000 m²**
Yıllık Isıtma Gün Sayısı	**120**
Yıllık Soğutma Gün Sayısı	**180**
Isıtma/Soğutma Sistemi	**Doğalgaz/ Split Klima**
Yalıtım Durumu	**Yalıtımsız**
Yıllık Ortalama Enerji Tüketim(2022)	**299 TEP (Elektrik) 151 TEP (Doğalgaz)**
Ana Kalorifer Dairesinin 2. Isı Dağıtım Merkezine Mesafesi	**120 metre**

Araştırma kapsamında bir kamu hastanesi olan Atatürk Devlet Hastanesi uygulama binası olarak seçilmiştir. Bina bilgileri Tablo 1'de verilmiştir. 7/24 hizmet veren bir kamu binası olduğundan enerji verimliliği uygulamalarında yüksek enerji verimliliği elde edileceği düşünülmüştür.

Atatürk Devlet Hastanesi kapalı alanı 10.000 m² ve yıllık enerji tüketimi 250 TEP üzeri olduğu için 27/10/2011 tarihli ve 28097 sayılı Resmi Gazetede yayımlanan "Enerji Kaynaklarının ve Enerjinin Kullanımında Verimliliğin Artırılmasına Dair Yönetmelik uyarınca enerji yöneticisi görevlendirilmesi yapılan bir binadır.

Gerçekleştirilen Enerji Verimliliği Uygulamaları

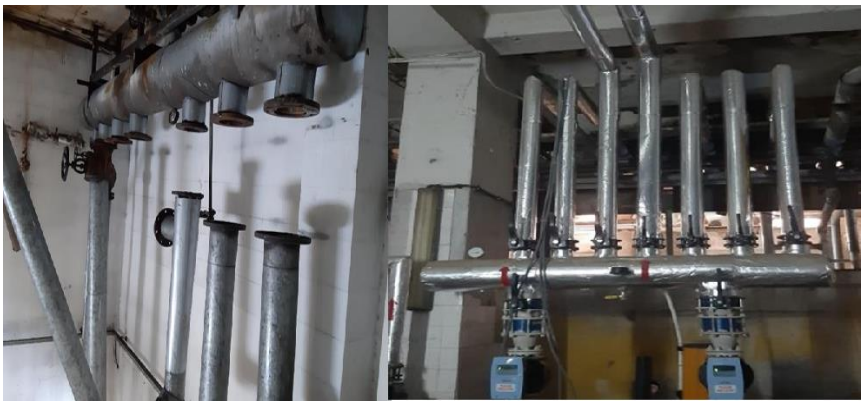
Kapı ve pencerelerden kaynaklanan kaçaklar tespit edilerek ve sızdırmazlığın sağlanmasına yönelik gerekli tamirat işlemleri yapılmıştır.

Hastane ortamında birçok hasta tarafından pencere açma gereksinimi duyulmaktadır. Klimalar devrede iken pencere açık tutulduğundan soğutmada kullanılan enerji sarfiyatı yüksek olabilmektedir. Bu nedenle, pencere

açıkken klimanın çalışmasını engellemek için tüm pencerelere Resim 2'de gösterilen manyetik anahtarlar takılmıştır. Böylece pencereler açıldığında klima devre dışı kalmaktadır.

Resim 2 Pencerelere takılan manyetik anahtar görüntüsü

Isıtma ve soğutma sistemlerine ait boru ve kanallarda yalıtım olmayan bölgelere Resim 3'te görüldüğü gibi vana ve flanşlar da dahil olmak üzere yalıtım yapılmıştır.



Resim 3 Revizyon öncesi eski yalıtımsız ve revizyon sonrası ısıtma sistemi yalıtımlı

Verimsiz ve ekonomik ömrünü tamamlamış 1994 üretimi iki adet buhar kazanı 2019-2020 yıllarında daha verimli kazanlarla değiştirilmiştir. Eski buhar kazanları ısıtılacak olan binadan120 metre mesafede ayrı bir blokta konumlanmış, binanın ısıtılabilmesi için buhar yaklaşık 120-130 °C sıcaklığa ulaştıktan sonra bahsi geçen binaya 70 °C olarak gelmekteydi. Arada çok büyük enerji kayıpları olduğundan, verimsiz buhar kazanları Resim 4'de görüldüğü gibi yeni sistem sıcak su kazanlarıyla değiştirilmiş ve borulama sistemi dış ortamda olduğundan yalıtımı sağlanmıştır. 2018 ve 2020 yılları enerji tüketimleri karşılaştırıldığında, 2018 yılında tüketim 415,19 TEP, 2020 yılında ise 202,69 TEP olarak gerçekleşmiştir. Kazan dairesinde yapılan revizyon işlemi sonrasında yıllık 212,5 TEP enerji tasarrufu sağlanmıştır.

Resim 4 Eski Buhar Kazanı ve Yeni Sulu Kazan

Elektrik faturalarında reaktif cezayı önlemek amacı ile Resim 5'te gösterildiği üzere sayaca modem takılarak uzaktan takip edilebilirliği sağlanmıştır.

Resim 5 Hastane Sayacına Takılan Uzaktan Okuma Modemi

Hedeflenen enerji verimliliğine esas uygulamalar kapsamında, elektrikli cihazların ve aydınlatma ekipmanlarının kullanılmadıkları durumlarda kapatılmaları, ayrıca uzun süre kullanılmayan elektrikli cihazların bekleme modunda bırakılmaması hakkında personele yönelik bilinçlendirme eğitimleri gerçekleştirilmiştir.

Hasta odalarında bulunan banyolarda çoğunlukla açık unutulan aydınlatma armatürlerine Resim 6'da görülen hareket sensörü takılmış, bozulan eski tip aydınlatma armatürleri, daha düşük güçteki LED'ler ile değiştirilmiştir. Bu sayede aydınlatma armatürlerinin açık unutulmalarına karşı önlem alınmış, aynı zamanda enerji tüketimi düşük olan armatürlerin kullanılması ile enerji tasarrufu sağlanmıştır.

Resim 6 Hareket Sensörü ve LED kullanımı

Hastane genelinde kullanılmakta olan 4x18 W gücündeki floresan lambalar bozuldukça Resim 7'de görüldüğü gibi 35 W gücündeki LED armatürlerle değiştirilmiştir. Böylece tehlikeli atık olarak sınıflandırılan ve balast bulunduran floresan armatür kullanımı azaltılmış, lambanın toplam gücünün %20 si kadar olan balast kayıplarının önüne geçilerek enerji verimliliği sağlanmıştır. Lamba başına enerji tüketimi balast kaybı dâhil 86,4 W olan (4x18 W +14,4 W) eski tip armatürler toplam tüketimi 35 W olan LED armatürler ile değiştirilerek armatür başına %59,5 enerji verimi sağlanmıştır. Yapılan hesaplamalar Tablo 2, Tablo 3 ve Tablo 4' te gösterilmiştir.

Tablo 2. 1 adet 4x18 w gücündeki bir armatürün tüketim verileri (ADM'nin Atatürk Devlet Hastanesine uyguladığı tarife üzerinden Kasım -2023 kW/h birim fiyatına göre hesaplanmıştır)

4x18 W Floresan Armatür Enerji Tüketim Maliyeti Hesabı					
4x18 w	Kullanılan Lamba Gücü	Balast Kaybı	Lamba Başına Güç	Adet	Toplam Güç (kW)
	72	14,4	86,4	1	0,0864
	Ortalama Çalışma Süresi	Enerji kWh	kwh birim	Aylık	Yıllık
	10	0,864	2,61	₺67,65	₺811,81

Tablo 3. 1 adet 35 w gücündeki bir LED armatürün tüketim verileri (ADM'nin Atatürk Devlet Hastanesine uyguladığı tarife üzerinden Kasım-2023 kW/h birim fiyatına göre hesaplanmıştır)

35 w LED Armatür Enerji Tüketim Maliyeti Hesabı					
35 w LED Armatür	Kullanılan Lamba Gücü	Balast Kaybı	Lamba Başına Güç	Adet	Toplam Güç (kW)
	35	0	35	1	0,035
	Ortalama Çalışma Süresi	Enerji kWh	kwh birim maliyet	aylık maliyet elektrik(TL)	yıllık maliyet elektrik(TL)
	10	0,35	2,61	₺27,41	₺328,86

Tablo 4 35 w gücündeki bir LED armatürün 4x18 w gücündeki bir armatüre oranla tasarruf verileri (LED fiyatı ÇŞB 2023 Poz tarifine göre montaj ve KDV dâhil fiyatıdır)

LED Armatürün 4x18 W Floresan Armatüre Göre Tasarruf Oranı					
LED Yatırım Maliyeti	**LED** (TL)	Adet	**LED** Yatırım Maliyeti (TL)	Tasarruf Maliyeti (TL)	Tasarruf Oranı (%)
	1190	1	1190	482,95	59,5
LED Armatür Amorti Süresi (Yıl)			2,46		

Resim 7 4x18 w armatürlerin 35 w **LED** Armatür ile değişimine bir örnek

Yapılan Çalışmalar Sonucunda Elde Edilen Veriler

Atatürk Devlet Hastanesi 2015 ve 2022 yılları arası elektrik enerji tüketimleri TEP cinsinden karşılaştırılmıştır. 2015 yılından 2019 yılına kadar elektrik tüketimi artarken yapılan verimlilik çalışmaları neticesinde 2019 yılı itibarı ile tasarrufa geçilmeye başlanmıştır. 2019 yılında 340,68 TEP, 2020 yılında 305,15 TEP, 2021 yılında 290,62 TEP elektrik enerjisi tüketimi gerçekleşmiştir.

Tablo 5'te 2015 yılı itibarı ile elektrik tüketimi bilgileri verilmiştir. Uygulama binasında 2018 yılından önce enerji verimliliği ile ilgili herhangi bir çalışma yapılmamıştır. Her sene bir önceki seneye göre elektrik enerjisi tüketiminde %10 artış öngörülmekteydi. Tablo 5'ten de anlaşılacağı üzere 2018 yılına kadar Hastanede bakılan hasta sayısının artması, personel sayısının artması buna paralel cihaz sayısının artması enerji tüketimini de her sene bir önceki seneye göre arttırmıştır. 2018 yılından sonra büyüme aynı ivme ile devam ettiği halde enerji verimliliğinde yapılan çalışmalar sonucu elektrik tüketiminde azalma görülmektedir. 2023 yılında elektrik tüketimi Tablo 6'da belirtildiği gibi ilk on ay için (2022 yılına göre) %3,48 azalmıştır.

2019 Yılı içerisinde ihale yoluyla kalorifer kazan daireleri tadilatı gerçekleştirilmiş olup; 2018 ve 2020 yılları doğalgaz tüketimleri TEP cinsinden karşılaştırıldığında, 2018 yılında 415 TEP, 2020 yılında 202 TEP doğalgaz tüketimi gerçekleşmiştir. Doğalgaz kullanımında %51.18 tasarruf sağlanmıştır.

Tablo 5. 2015-2022 Yılları Elektrik Tüketim verisi ve tasarruf miktarı

Atatürk Devlet Hastanesi Elektrik Sarfiyatı 2015-2022 karşılaştırılması (Elektrik Tüketimi)		
Fatura Dönemi	Tüketim (TEP)	Tasarruf Miktarı (Önceki Yıla Göre) %
2015	245,42	
2016	276,48	-12,66
2017	294,8	-6,63
2018	326,77	-10,85
2019	340,69	-4,26
2020	305,15	10,43
2021	290,62	4,76

Tablo 6 2022-2023 Yılları Elektrik Tüketim verisi ve tasarruf oranları

ATATÜRK DEVLET HASTANESİ 2022-2023 YILLARI ELEKTRİK TÜKETİMİ KARŞILAŞTIRILMASI			
AY	**2022 (TEP)**	**2023 (TEP)**	**TASARRUF(%)**
OCAK	25,533084	21,56	15,55
ŞUBAT	22,171106	20,46	7,71
MART	25,089999	19,18	23,55
NİSAN	18,710955	16,79	10,27
MAYIS	19,221005	18,25	5,05
HAZİRAN	25,279846	21,59	14,61
TEMMUZ	29,062152	32,96	-13,42
AĞUSTOS	31,526583	33,40	-5,94
EYLÜL	23,422339	25,81	-10,20
EKİM	18,429435	20,15	-9,36
TOPLAM	238,446504	230,16	3,48

Yakın Gelecekte Gerçekleştirilmesi Planlanan Enerji Verimliliği Çalışmaları

Hastane çatısında bulunan ancak pasif olan 18 panelli güneş enerji sistemi çalışır duruma getirilirse 36 kW/h gücünde su ısıtma kapasitesi elde edecektir. Bu durumda su ısıtmak için kullanılan enerjiden saatte 36 kW/h tasarruf sağlanacaktır.

Hastane dış cephesinde mantolama bulunmamaktadır. Mantolama yapılması hem soğutma maliyetini hem de ısıtma maliyetini düşürecektir.

Hastane merkezi soğutma sistemi bulunmadığından soğutma split klimalar ile yapılmaktadır. Merkezi Soğutma sistemi kurulması enerji tasarrufu sağlayacaktur..

Hastane çatısına Fotovoltaik (PV) güneş enerji sistemi kurulabilir.

SONUÇLAR

Bu çalışma kapsamında 7/24 çalışma esasına dayanan bir hastane binası uygulama binası olarak seçilmiştir. Gerçekleştirilen enerji verimliliği uygulamaları kapsamında eski buhar kazanlarının yeni sulu kazanlarla değiştirilmesi ile %51,18 oranında daha az doğalgaz tüketimi gerçekleşmiştir. Ayrıca gerçekleştirilen uygulamalar sayesinde 2020 yılında %10,42, 2021 yılında %4,76, 2022 yılında %16,96, 2023 yılının ilk on ayı için %3,48 oranında elektrik tüketiminde enerjisi verimliliği sağlanmıştır.

TEŞEKKÜR

Yazarlar, Aydın İl Sağlık Müdürlüğü, Kamu Hastaneleri Başkanlığı ve Destek Hizmetleri Başkanlığı'na, bağlı hastanelerde enerji verimliliği çalışmaları yapmak, yapılan çalışmaların verilerini analiz etmek ve akademik amaçla kullanmak için verdikleri izinden dolayı teşekkür eder.

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ANALYSIS OF THE WIND LOAD ON THE BUILDING IN TURBULENT FLOW IN OPENFOAM

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ABSTRACT

Nowadays, as the world's population grows, the number of high-rise buildings being built has significantly increased. This development causes concern about how wind may affect these buildings even more critically. Wind can interact with flexible structures, considerably enhancing wind forces and building sway. Extreme winds are often erratic and can cause structural deformation. Such irregular wind flows are called turbulent flow. This study aims to model turbulent wind flow around a building using OpenFOAM solver with Large Eddy Simulation (LES) and the pisoFoam solver with a logarithmic inlet profile.

Keywords: Wind, Turbulence, OpenFoam, LES, pisoFoam.

Introduction

Computational Fluid Dynamics (CFD) involves obtaining solutions of the fundamental equations that define fluid motion based on numerical methods. Analytical solutions to these equations are not available except for some basic problems due to the nonlinear nature of the equations. On the other hand, experimental research methods are costly, time-consuming and require expertise. In this respect, CFD has become an important research method in examining both academic and industrial problems, thanks to the rapidly developing computer technology. Aerodynamic and hydrodynamic calculations, thermal analyses, multiphase flow studies, performance can be performed, and non-Newtonian flows and phase changes can be modeled. Using this method, the components that create a system or the entire system can be tested in a virtual environment [1-5].

Turbulence is the irregularity of a fluid in motion. In fluid dynamics, turbulence or turbulent flow is a flow regime characterized by chaotic changes in pressure and flow rate. Unlike laminar flow, where fluid flows in regular layers, turbulent flows mix and move chaotically. The regime of the flow can be estimated by the dimensionless Reynolds number, which indicates the ratio of inertial forces to viscosity forces. Although high Reynolds numbers can be considered as a harbinger of the turbulent regime, the Reynolds number at which this transition occurs depends on many factors, and in different problems, a transition to the turbulent regime may occur at a much higher or lower Reynolds number [2-12].

OpenFOAM is a finite volume based differential equation solver. Conservation equations for fluid motion involve transforming the equations into a system of algebraic equations after integration and interpolation processes in each cell of the flow region divided into a finite number of parts. This system of algebraic equations contains many unknowns and uses modern computers to solve them. OpenFOAM was developed with the help of object-oriented programming, in C++ language and based on tensor algebra. It is a platform that can provide solutions for polyhedral network cells with non-overlapping and planar surfaces, and therefore can be used with high accuracy in solving industrial problems as well as academic problems. The ability to perform parallel computing for any desired number of processors, as well as the large number of algebraic

equation system solvers that come with the standard OpenFOAM setup, are key elements that rival commercial software in this field

Materials and Methods

The easiest way to create a new model in OpenFOAM is to proceed through the sample designs under the tutorials folder in the software. Due to OpenFOAM's capacity and strengths, it is used in industrial applications such as aerodynamics [13], turbomachines [14] and problems involving heat transfer [15].

There are solvers created for different physical situations under the tutorials folder. Using a solver suitable for the experimental model is a very important step in order to increase the accuracy of numerical study. In this study, pisoFoam solvent was used since the wind load on the building was examined.

PisoFoam (Pressure Implicit with Splitting of Operators) is a solver built into OpenFOAM and is often used for incompressible flow simulations. This solver uses a pressure-based algorithm and focuses on solving the velocity and pressure distribution in the flow field. It solves the Navier-Stokes equations (mass conservation, momentum equations) and the pressure-Poisson equation. In this way, accurate results are obtained for incompressible flows. The pressure-based algorithm uses an iterative approach to correct imbalances in the velocity and pressure field. The PisoFoam solver is suitable for flows with low Mach numbers (flows with low speed relative to the speed of sound). Incompressible flows are often used in situations such as liquid flows or low Mach number gas flows.

The graph shown in Figure 1 represents a turbulent flow recorded over time at a specific point in space. In Figure 1, the instantaneous velocity is given by u = U + u', where U represents the time-averaged velocity and u' is the velocity fluctuation over time. Since the change over time is not repeated periodically, such flows are random and chaotic and are called turbulent flows [16].

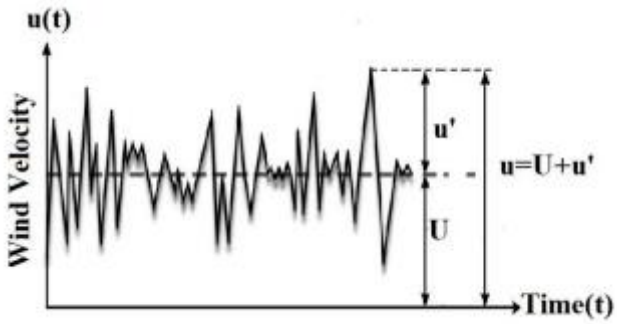


Figure 1. Wind Speed at a Point in Time

Reynolds Number (Re), a dimensionless parameter, is a value that helps distinguish between laminar and turbulent flow. Re is defined by the following equation:

The larger eddies that can be captured by the grid are calculated directly with LES solver, while smaller eddies are modeled with the Subgrid Scale Stress (SGS) model, similar to RANS methods. Here, the Smagorinsky–Lilly SGS model is used as the SGS model and predicts the equivalent viscosity of smaller eddies for turbulence.

These three turbulence modeling methods are also shown in Figure 2 according to the eddy size change in the wind spectrum. In Figure 2, an eddy is shown as a circular vortex. As can be seen, in DNS all eddy sizes are resolved, while in RANS the effect of all eddies with different length scales is modeled. However, in LES, large eddies are resolved while the effect of smaller eddies is modeled.

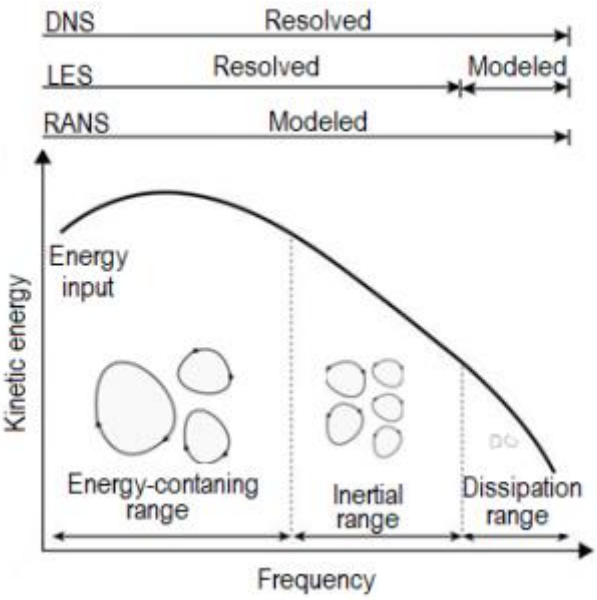


Figure 2. Comparison of Different Turbulence Models According to Eddy Size Change

The complexity of turbulence means that it is impossible to accept any one model of turbulence as a universal model. Therefore, RANS turbulence models should be considered engineering approaches rather than a scientific law. Turbulence is locally dynamic in some flows, and time averaging completely eliminates these turbulent features. LES approximates these local flow variables. Therefore, DNS and LES have gained importance in recent years. While RANS models deal with time-averaged fields, even temporal values are not calculated even if they are larger than the grid size. On the other hand, in LES all eddies larger than the grid size is calculated. For example, as an example of analogy, RANS approximates the number of people crossing. However, in LES, we can capture every person's movement at any time.

Although DNS and LES provide increased ability to predict instability in the flow field, DNS can only be used for low Reynolds number flows and simple geometries. The flow details provided by DNS are not required for design purposes. For engineering applications, average fields may be suitable. High-resolution flow fields obtained from LES, rather than the modeled effect of the RANS k-ε model, may receive greater interest in industry in the future.

Wind loads required for the structural design of buildings can be obtained using numerical (CFD) models. In this study, turbulent wind around a building is modeled using OpenFOAM. LES is used to capture turbulence effects in wind flow. To calculate the wind flow around a building, a region called the calculation area shown in Figure 3 must be taken into account. The flow characteristics used as initial conditions are given in Table 1. To accurately predict wind load, a numerical model must be able to capture real flow physics. In the real boundary layer, the velocity near the ground is zero due to friction and increases with height, so the wind speed near the ground is approximated by the logarithmic velocity profile. Similarly, the standard wall function is applied to ground walls to capture the high velocity gradient.

The BlockMeshDict file is a configuration file used to create mesh in OpenFOAM. This file allows the determination of geometry, cell arrangement, boundary conditions and other parameters and contains the structural information necessary for the mesh creation process.

```
convertToMeters 1;

vertices
(
    (-24 0 -75)
    (198 0 -75)
    (198  48 -75)
    (-24  48 -75)
    (-24 0 90)
    (198 0 90)
    (198  48 90)
    (-24  48 90)
);

blocks
(
    hex (0 1 2 3 4 5 6 7) (60 30 20) simpleGrading (1 1 1)
);
```

Figure 3. BlockMesh Matrix

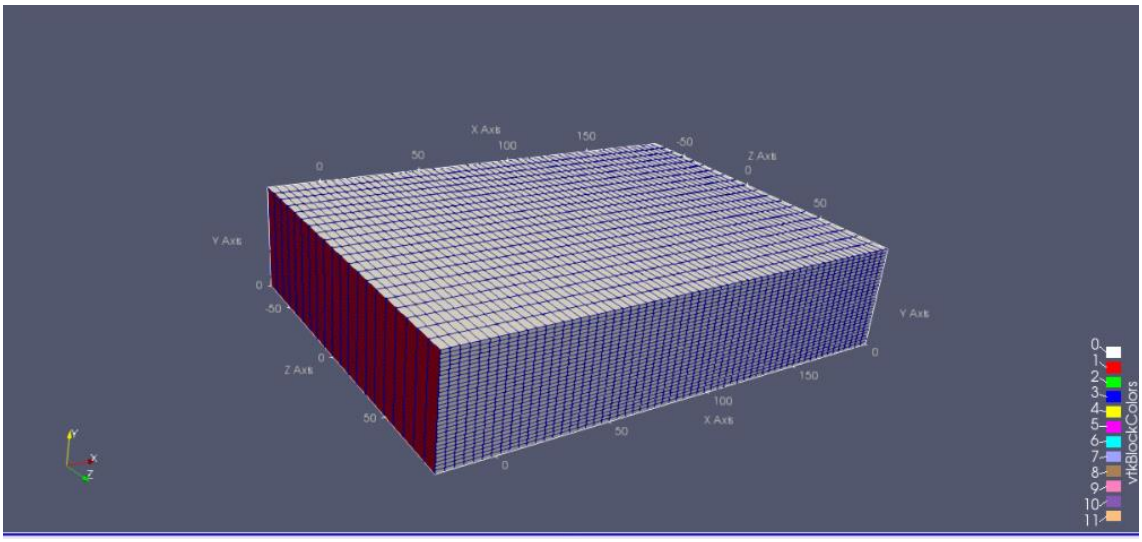


Figure 4. Description of BlockMesh

SnappyHexMesh is a tool, part of OpenFOAM, that enables high-quality, surface-based 3D hexahedral mesh creation. This tool uses geometry data from STL (Stereolithography) or another surface format used to represent complex geometries.

SnappyHexMesh supports a variety of geometries, from simple plane geometries to objects with complex structures. This tool automatically creates a mesh of hexagonal prism cells using surface data. Hexagonal prism cells are one of the preferred cell types for flow simulations because they provide better results with smooth surfaces and node placement.

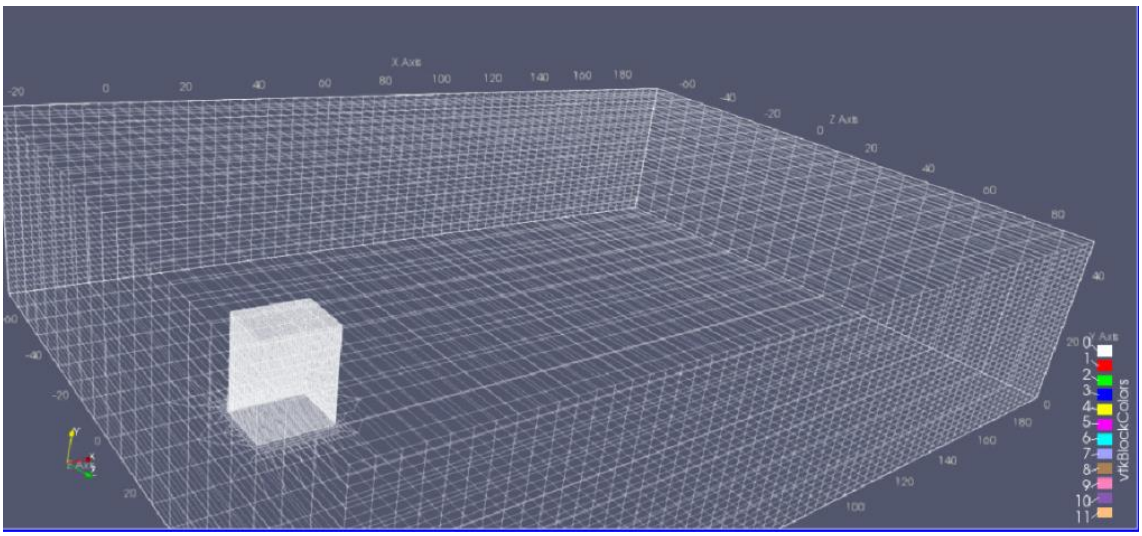


Figure 5. Description of SnappyHexMesh

Findings and Discussion

The inlet velocity 20 m/s, 4 seconds analysis performed with pisoFoam solver using LES turbulence modeling.

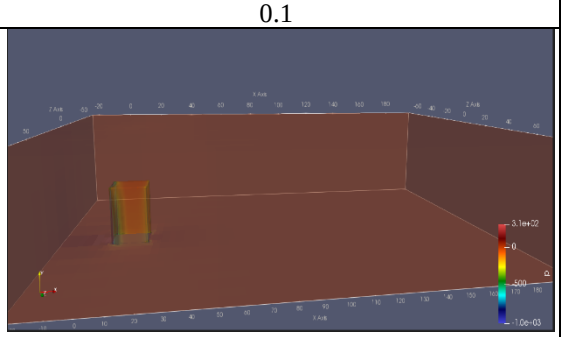
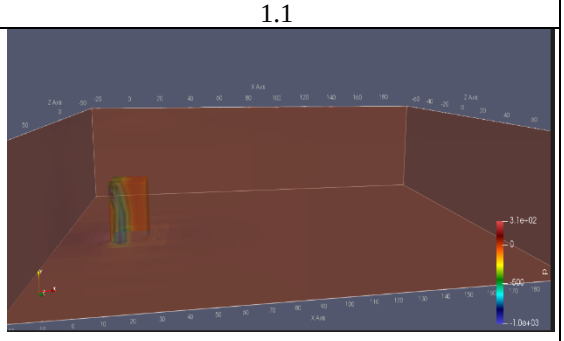
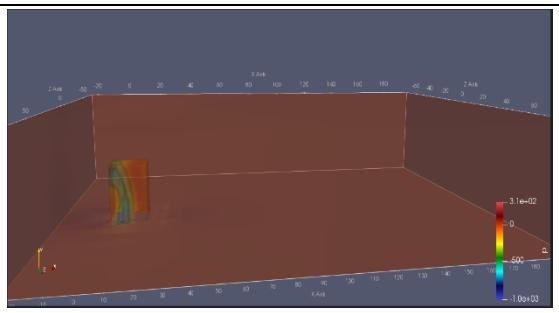
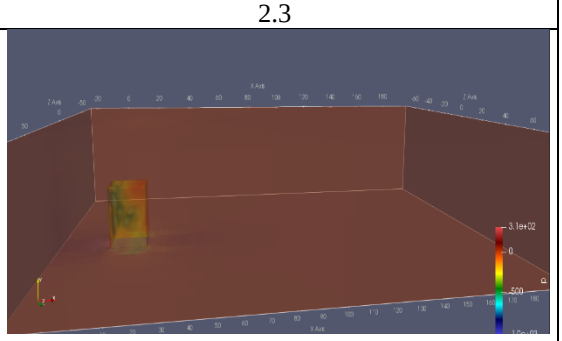
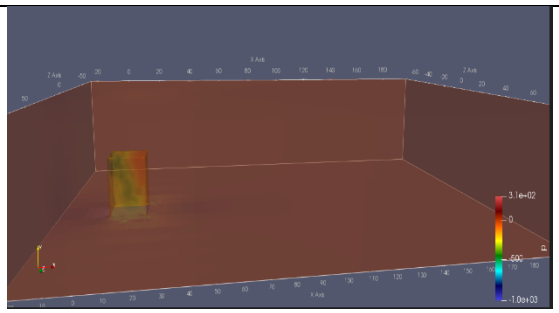
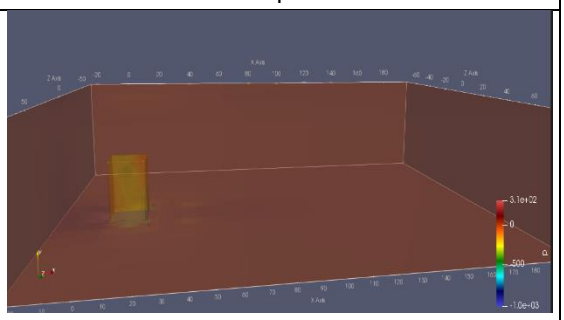
Time (s)	0.1	1.1
Pressure distribution		
Time	1.5	2.3
Pressure distribution		
Time	3	4
Pressure distribution		

Figure 6. Pressure distribution on the building at different times

A pressure loss was observed at the inlet during 0.1 seconds as the fluid accelerated towards the building. This means that the flow accelerates as it approaches the building, preparing the flow for impact. Boundary layer thickening and flow separation were observed when the total pressure loss was encountered at 1.5 seconds and 3 seconds. At this point, separation and instability may have occurred in areas where turbulence intensified, and the fluid began to move away from the surface. It was observed that at the 4th second, the boundary layer fluid spread further towards the surface. This marks a phase in which the boundary layer expands, and surface interaction increases.

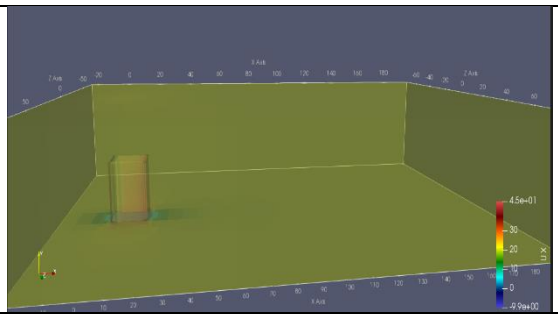
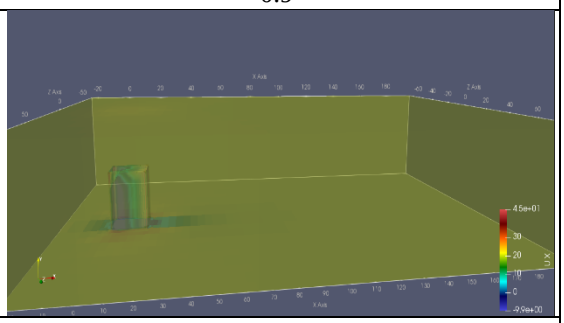
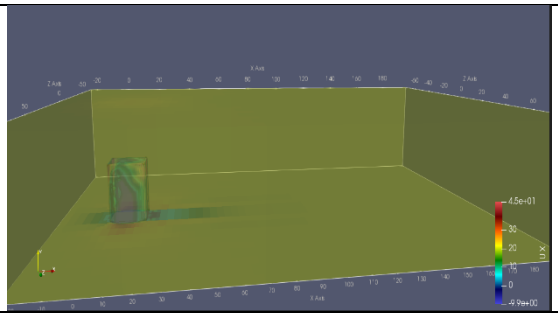
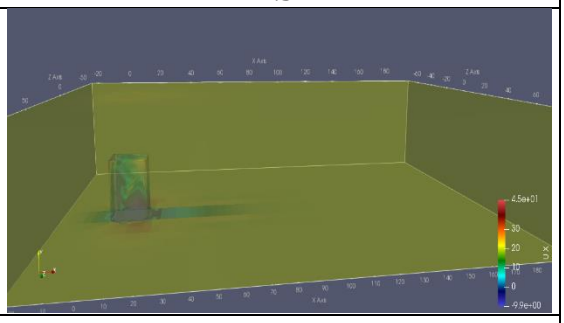
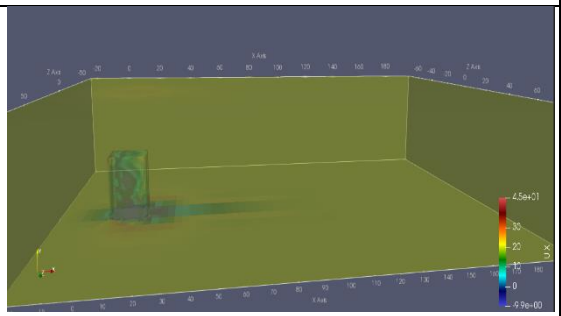
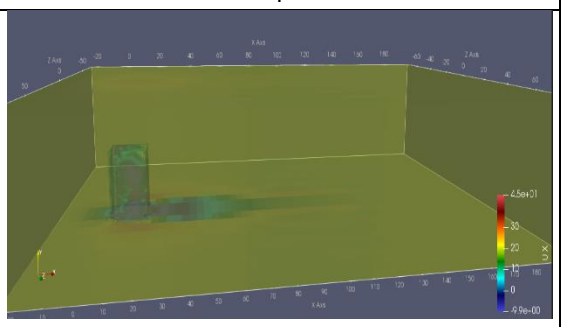
Time (s)	0.1	0.9
Velocity distribution		
Time	1.6	2.3
Velocity distribution		
Time	3	4
Velocity distribution		

Figure 7. Velocity distribution on the building at different times

XxxxIn 0.1 seconds, a decline in velocity was observed on the front wall due to the impact of the fluid hitting the building. This impact effect reduced the velocity of the flow at the front wall and caused it to slow down towards the surface of the building. From 0.1 s onwards, boundary layer thickening was observed on the top and side walls. This indicates that the flow slows down in these regions and the boundary layer thickens. The thickening of the boundary layer causes the fluid to flow more slowly in regions closer to the structure surface. It was observed that the fluid spread over the object and lost velocity in the 1.6 second and 3 second time periods. This indicates that the flow is distributed around the object and the velocity decreases in regions where the boundary layer moves away from the structure surface.

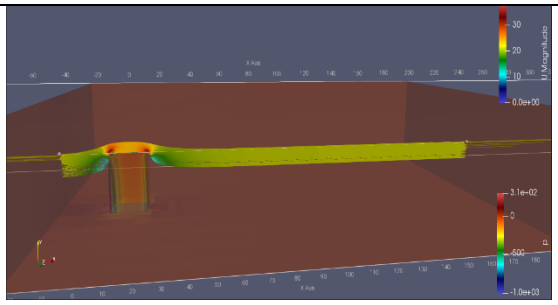
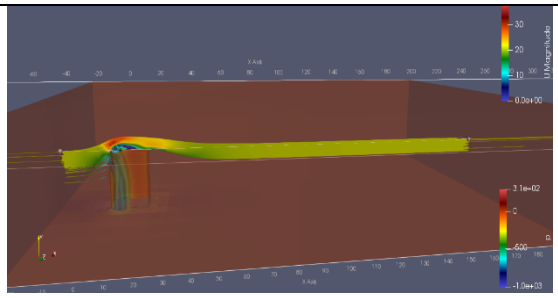
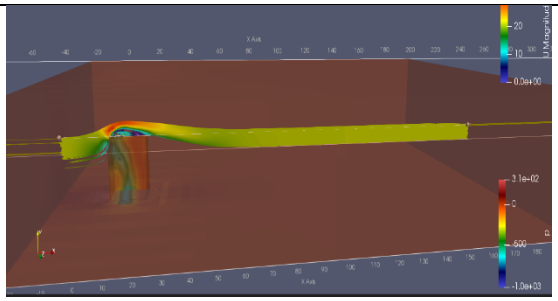
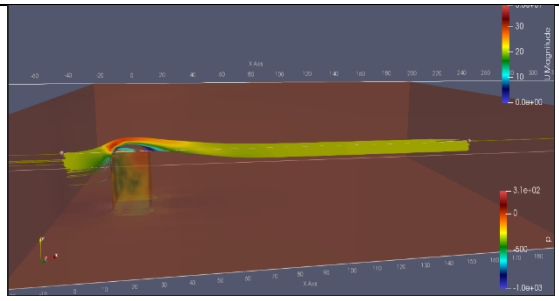
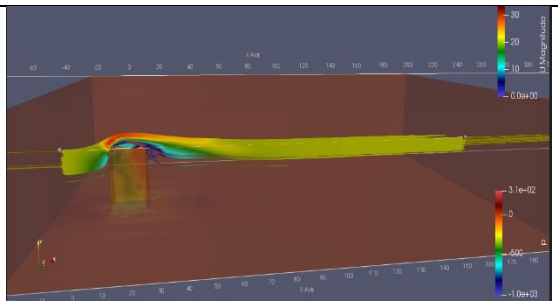
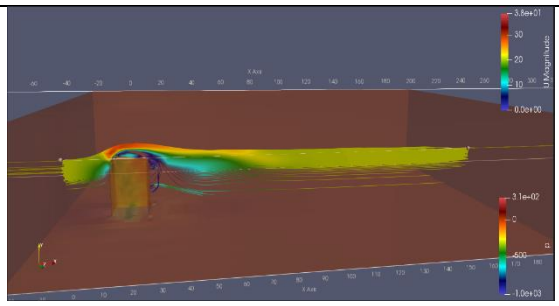
Time (s)	0.1	1
Fluid motion		
Time	1.6	2.3
Fluid motion		
Time	3	4
Fluid motion		

Figure 8. Fluid motion on the building at different times

A reduction of velocity was observed at the sharp ends of the front surface and the sharp ends of the rear surface due to the impact of the fluid hitting the building in seconds. This impact effect reduced the speed of the fluid on the front surface and rear surface and caused it to slow down towards the surface of the building. From 0.1 s onwards, boundary layer thickening and pressure loss were observed on the upper and side walls of the fluid. This indicates that the fluid slows down in these regions and the boundary layer thickens. Thickening of the boundary layer causes the fluid to flow more slowly in areas closer to the structure surface and causes pressure loss. It was observed that the speed and pressure increased on the surface of the building where the flow was vertical in 1.6 seconds, while the pressure and speed were low on the back surface. This shows how the velocity and pressure of the fluid changes as it hits the structure surface. It was observed that vortices formed due to the change in speed of the fluid starting from the 3rd second. This indicates that the fluid is moving in a turbulent manner and eddies are forming.

Conclusion and Recommendations

In the study, the pressure loss, flow and velocity distributions caused by the wind load on the building were examined through OpenFoam. The building was designed in three dimensions and analyzes were run. The

wind load was 20 m/s to hit the building. Flow separation was observed as a result of pressure loss and boundary layer thickening at the front surface and sharp ends of the 20 m/s part.

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PERFORMANCE IMPROVEMENT OF PEMFC BASED ON REDUCING SIZE OF THE SQUARE FLOW CHANNEL: A 3D CFD APPROACH

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ABSTRACT

Proton exchange membrane fuel cells (PEMFCs) have significant potential to generate clean, renewable and sustainable energy and reduce emissions to mitigate climate change. PEMFCs comprise distinct components, namely, anode and cathode bipolar plates with flow channels, catalyst layers, gas diffusion layers and a membrane. The shape of gas flow channels affects the flow velocities, gas species mass fractions and cell performance. In this study, a three-dimensional computational model is improved via the PEMFC module of ANSYS FLUENT software. The square channel configurations with widths and depths ranging from 0.2 to 0.8 mm are generated by modifying the reference channel having 1 mm depth and width. The results showed that reducing dimensions of the square channel augmented the current density due to enhancing flow velocity in the anode and cathode channels with the disadvantage of an elevated pressure drop. The configuration having a 0.2 x 0.2 mm square channel enhances the current density to 2.95 A/cm^2 compared to the reference case with a current density of 1.25 A/cm^2 at 0.4 V. But, taking into account pressure loss along the flow channels, a 0.4 x 0.4 mm square channel enhancing current density with a rise of 68% in comparison the base case at 0.4 V is a good option to improve the cell performance.

Keywords: PEMFC, CFD, Channel cross-sectional dimensions, Current density, Pressure drop.

Introduction

Fossil fuels are carbon based fuels such as crude coal, natural gas and oil which are the primary energy sources for the power generation. But they are non-renewable and burning them leads to emissions (CO_2, NO_x, particles, etc.) which cause the climate change and have the worst effects on the environment and our health. Therefore, researchers have been improving new technologies on generating alternative power sources. Fuel cells are the encouraging power sources since they are energy converters which transform the fuel chemical energy to electricity with simplicity, high power, low pollution and quiet, (Barbir, 2013). The PEM fuel cells (PEMFCs) have key advantages in comparison to other types such as low operating temperature, durability for a long lifetime, high energy density and a wide power range (Wu, 2016). These benefits favor PEMFCs for distinct applications, such as transportation, portable and backup power applications (Spiegel, 2008).

A PEMFC is a multi-part device consisting of the bipolar plates with flow channels engraved and a membrane electrode assembly (MEA) consisting of a membrane, diffusion layers (GDLs) catalyst layers (CLs) at anode and cathode (Xing, 2019). The bipolar plate distributes hydrogen and oxygen throughout the channel. H_2 molecules are broken down into electrons and protons at the anode CL. Protons moves toward the membrane whereas electrons travel to the cathode current collector by the electrical circuit. The electricity, water and waste heat are generated with combining electrons, protons and oxygen molecules at the cathode CL.

The flow channels are very crucial for the enhancement of the cell performance. Their shapes affect the distributions of gas species at the reacting area. Namely, the channel geometry determines the reactant supply to anode and cathode CL where the electrochemical reactions happen. But the geometrical modifications of the channels also impact pressure drop through the channel. Researchers have analysed the impacts of altering the channel shapes on the augmentation of PEMFC efficiency.

Cooper et al. (2017) examined the influence of the length-to-width ratio of channels having interdigitated flow fields on PEMFC performance improvement. It was seen that decreasing the aspect ratio by reducing the channel length led to higher overall performance. Chowdhury et al. (2017) found that both channel and land widths were equally significant to enhance the current density and the flow channel with 1 mm channel and

land width could be best choice regarding pressure drop and current density in the channel. Carcada et al. (2021) scrutinized the impact of the serpentine channel numbers (7, 11, and 14) and cross-sectional size on performance of PEMFC having a large active area. Their results demonstrated that a rise in number of serpentine channels or a decrease in the channel width to land width improved the cell performance, particularly at high current density. Kaplan (2021) scrutinized 15 case studies gained by modifying the width and depth of the flow channel (0.2-1.6 mm) for 1 mm constant depth and width. The findings indicated that current density and velocity in the flow channel augmented with decreasing depth and width of the channel compared to base case with the channel cross-section of 1 x 1 mm (channel width x depth) at the cost of high pressure loss.

Brakni et al. (2023) examined the impact of distinct flow field channels having constriction and widening sections at the middle of the channel on the PEMFC performance. They noticed that the configuration with a constricting hydraulic diameter of 50% showed better performance due to this configuration enhancing fluid velocity and thus more uniform velocity distribution but higher pressure loss. Dong et al. (2024) improved a three-dimensional (3D) model to study the mass transport features and performance of the cell with novel two-block structures inside the channel at the cathode. Their findings revealed that the novel two-block structures augmented oxygen concentration thanks to convection influence of these structures and thus enhanced PEMFC performance with a slight increase in pressure drop.

The goal of the current work is to examine the influence of the distinct square flow channel cross-sections on the PEMFC performance.

Materials and Methods

The 3D geometric model employed in this work is built with the help of SOLIDWORKS software. After this, the structured mesh is produced using Sweep Method in ANSYS Meshing.

The model comprises of a membrane anode and cathode CLs, GDLs, flow channels and current collectors to determine physical domains included in the Fuel Cell module (ANSYS, 2011) in Figure 1. Different configurations are obtained by decreasing the base flow channel depth and width from 1 mm to 0.2 mm with an interval of 0.2 mm in Figure 2.

The geometrical features utilized in the CFD analysis in Table 1 are based on the experimental study performed by Wang et al. (2003).

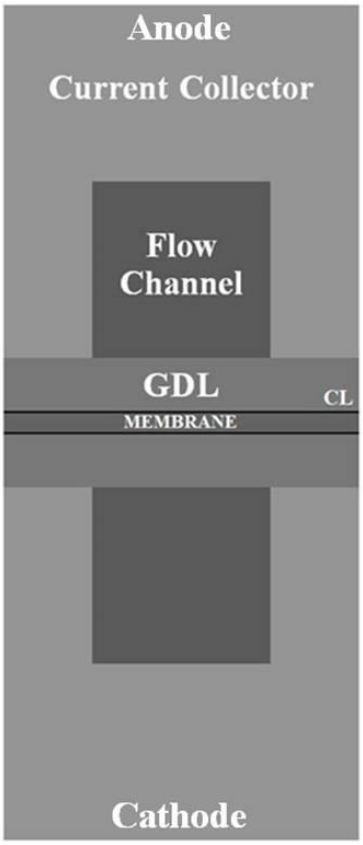

Figure 1. Cross-sectional view of PEMFC model

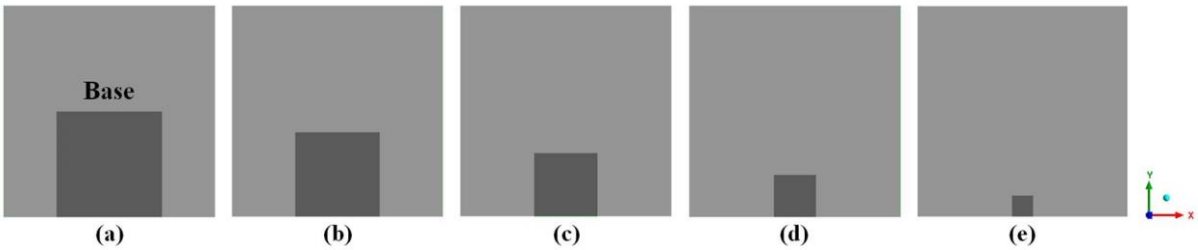

Figure 2. Flow channel configurations: a) base (1 x 1 mm), b) 0.8 x 0.8 mm c) 0.6 x 0.6 mm d) 0.4 x 0.4 mm e) 0.2 x 0.2 mm

Table 1. The geometrical characteristics of the model

Parameter	Value	Unit
Membrane	108	µm
CL thickness	12.9	µm
GDL thickness	300	µm
Channel width	1	mm
Channel height	1	mm
Cell width	2	mm
Cell length	70	mm

The parameters and operating conditions employed in the CFD analysis are listed in Table 2.

Table 2. Features and operating conditions used in the 3D CFD simulation

Parameter	Value	Unit
GDL and CL viscous resistance (Kahveci and Taymaz, 2018)	1×10^{12}	$1/m^2$
GDL and CL porosity (Kahveci and Taymaz, 2018)	0.5	-
CL surface/volume ratio	200000	1/m
Reference exchange current density (anode and cathode)	4000 and 0.1	A/m
Anodic and cathodic transfer coefficient at anode and cathode (Wang et al., 2003)	0.5 and 2	-
Anode inlet mass flow rate (Kaplan, 2022a)	5.40×10^{-6}	kg/s
Cathode inlet mass flow rate (Kaplan, 2022a)	3.29×10^{-5}	kg/s
Anode inlet H_2 and H_2O mass fraction (Kaplan, 2022b)	0.2 and 0.8	-
Cathode inlet O_2 and H_2O mass fraction (Kaplan, 2022b)	0.2 and 0.1	-
H_2O and H_2 reference diffusivity (Biyikoglu and Alpat, 2011)	7.33×10^{-5}	m^2/s
O_2 and other species reference diffusivity	2.13×10^{-5} and 4.9×10^{-5}	m^2/s
The cell temperature	343	K
Open-circuit cell voltage	0.94	V

The flow is regarded as steady state, incompressible and laminar. It is supposed that gas species behave like perfect gases. The MEA is considered as isotropic and homogenous porous media.

The equations employed in the PEMFC model are summarized in Table 3.

Table 3. The governing equations employed in the PEMFC model

Governing	Mathematical expressions
Continuity	$\nabla(\rho\vec{u}) = 0$
Momentum	$\frac{1}{(\varepsilon)^2}\nabla(\rho\vec{u}\vec{u}) = -\nabla P + \nabla(\tau) + S_m$
Energy	$\nabla(\rho c_p \vec{u} T) = \nabla(k^{eff}\nabla T) + S_e$
Species	$\nabla(\vec{u}C_i) = \nabla(D_i^{eff}\nabla C_i) + S_i$
Charge	$\nabla(\sigma_{mem}\nabla\phi_{mem}) + R_{mem} = 0,\ \nabla(\sigma_{sol}\nabla\phi_{sol}) + R_{sol} = 0$

The constant mass flow rates whose values given in Table 2 are assigned the flow channel inlets at the anode and cathode. Atmospheric pressure is specified for the flow channel outlet at the anode and cathode. All other faces are wall boundary conditions. Top faces of anode and cathode current collectors are specified as terminals. The potentials of anode and cathode terminals are 0 V and 0.39-0.92 V for the validation of the CFD model.

Findings and Discussion

The PEMFC model is validated using the measured data obtained by Wang et al. (2003) in Figure 3.

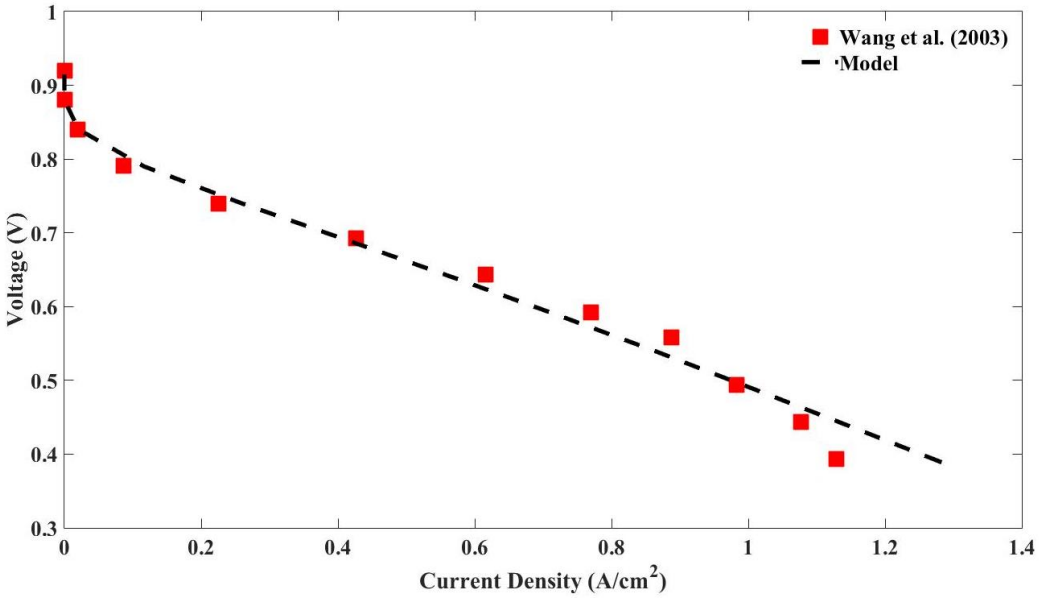

Figure 3. Validation of the PEMFC model with the measured data (Wang et al., 2003)

As illustrated in Fig. 3, the estimated results gained by the PEMFC model are a well agreement with experiment, especially at lower and medium current densities whereas the overprediction is observed at higher current densities. This is probably due to the current model not considering water (liquid) presence in the porous layers which leads to decreasing the porosity of the layers and augmenting species mass transfer resistance. Figure 4 shows the estimated current densities for the variation of the depth and width of the channels between 0.2 and 1 mm at 0.4 and 0.6 V.

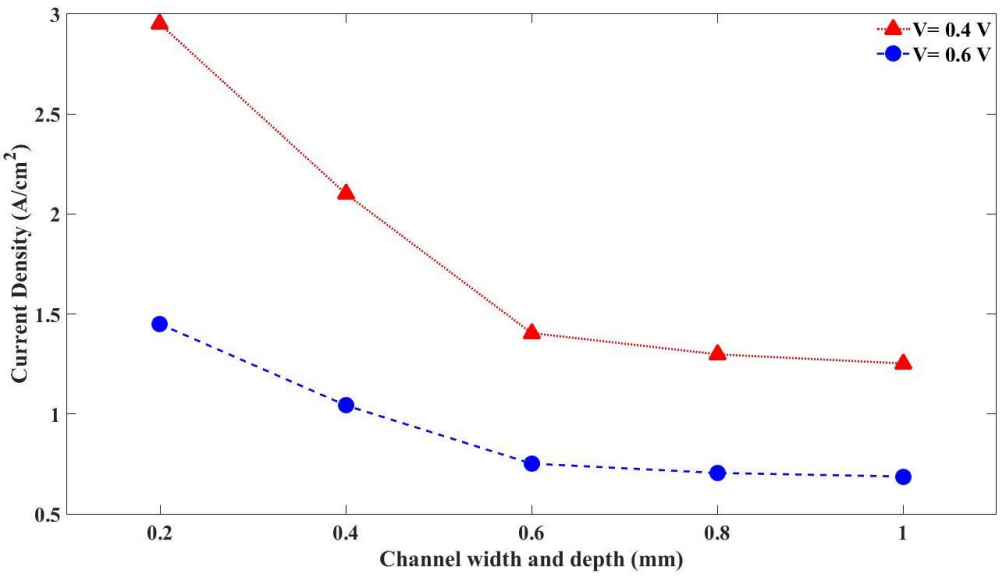

Figure 4. Change of current density as a function of channel width and depth at 0.4 and 0.6 V

The current density slightly increases between 0.6 and 1 mm channel width and depth in Figure 4. After this, current density considerably enhanced with a decrease in channel width and depth from 0.6 to 0.2 at 0.4 and

0.6 V. Therefore, the maximum current densities of 2.95 and 1.45 A/cm^2 are gained with the configuration with the channel cross-section of 0.2 x 0.2 mm at 0.4 and 0.6 V, respectively.

Figure 5 illustrates the oxygen mass fraction contours in the cathode flow channel, GDL and CL at the middle of the cell length for square channels whose cross sections of 1 x 1 mm (the base) and 0.2 x 0.2 mm at 0.4 V.

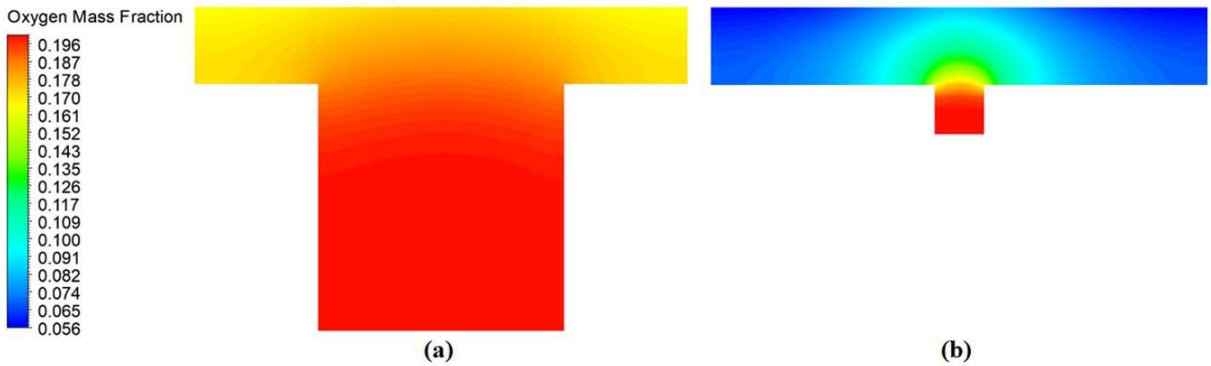

Figure 5. Oxygen mass fraction contours in the cathode flow channel, GDL and CL at the midpoint of the cell length for channel sizes of (a) 1 x 1 mm (the base) and (b) 0.2 x 0.2 mm

It is clear in Figure 5 that decreasing channel width and depth to 0.2 mm increases consumption of oxygen in CL and GDL in comparison to the base case at 0.4 V. Since 0.2 x 0.2 mm channel cross-section case produces higher current density in Figure 4, it consumes more oxygen for the reaction in the cathode CL in comparison to the base case at 0.4 V.

Figure 6 demonstrates the water mass fraction contours in the cathode flow channel, GDL and CL at the middle of the cell length for square channels whose cross sections of 1 x 1 mm (the base) and 0.2 x 0.2 mm at 0.4 V.

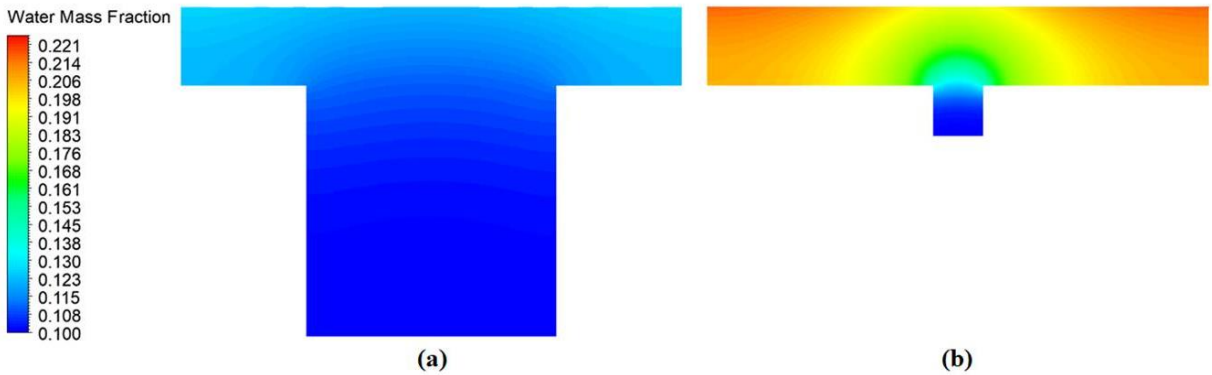

Figure 6. Water mass fraction contours in the cathode flow channel, GDL and CL at the midpoint of the cell length for channel sizes of (a) 1 x 1 mm (the base) and (b) 0.2 x 0.2 mm

It is apparent in Figure 6 that decreasing channel width and depth to 0.2 mm enhances water production in CL and GDL in comparison to the base case at 0.4 V. 0.2 x 0.2 mm channel cross-section case produces more water owing to this configuration generating higher current density in Figure 4 in comparison to the base case at 0.4 V. In conclusion, reducing flow channel cross-section dimensions leads to a decrease in oxygen and a rise in water and thus, augments the performance.

Table 4 indicates the current density and pressure drop results in the channels for varying square channel width and depth at 0.4 V.

Table 4. Current density and pressure drop results for different square channel configurations at 0.4V

Configurations	Current density (A/cm^2)	Pressure Drop	
		Anode (kPa)	Cathode (kPa)
Base	1.25	0.59	2.00
0.8 x 0.8 mm	1.30	1.39	4.85
0.6 x 0.6 mm	1.40	4.11	14.99
0.4 x 0.4 mm	2.10	18.74	68.21
0.2 x 0.2 mm	2.95	156.62	451.62

It is obvious in Table 4 that a decrease in the channel width and depth elevates the pressure drop in both channels. Besides the pressure drop at the cathode is much higher than that at the anode. This may be because of a mixture of gases in the channel at cathode being more complicated compared to that at the anode. The maximum current density is achieved with the configuration with 0.2 x 0.2 mm cross section but the cathode channel of this configuration produces the highest pressure drop of 451.62 kPa in Table 4. Taking into consideration pressure drop and current density in the channels, 0.4 x 0.4 mm channel case augmenting current density by 68% in comparison to the reference case at 0.4 V is better option to improve PEMFC performance.

Conclusion and Recommendations

In the present study, a 3-D numerical model is developed and validated by the measured data (Wang et al., 2003) to examine the effect of changing the square flow channel dimensions (width and depth) on PEMFC performance. The main findings are as follow:

- The lower the square channel width and depth leads to enhancing PEMFC performanceat 0.4 and 0.6 V.
- The maximum current density of 2.95 A/cm^2 is achieved with the configuration with a square channel of 0.2 x 0.2 mm cross-section at 0.4 V. Thus, in this configuration, oxygen concentration decreases and water concentration augment in the GDL and CL in comparison to the base configuration at 0.4 V.
- A reduction in dimensions of the square flow channel leads to higher pressure drop in the flow channels.
- Considering current density and pressure drop, the square channel of cross-section size 0.4 x 0.4 mm is more efficient option with 68% enhancement of the current density compared to base model provides better performance.

These outcomes emphasize the significance of the flow channel shapes in the design of efficient fuel cell systems. Future work includes the impact of distinct operating conditions and material properties on the cell performance which would improve the model suggested in this study.

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