CAFEO 41
ENGINEERING CONFERENCE PROCEEDING
2023

CAFEO ENGINEERING CONFERENCE
2023

CAFEO 41 INDONESIA 2023

AFEO

PERSATUAN INSINYUR INDONESIA
PII

Preface

Cafeo 41 Engineering Conference 2023

It is a great privilege for us to present the proceedings of the Cafeo 41st Conference to the authors and delegates of the event. This event showcases our dedication to engineering excellence, environmental sustainability, and economic progress. It serves as a valuable platform for knowledge sharing, collaboration, and strategic discussions among engineering professionals, policymakers, and industry leaders. This annual gathering serves as a unique platform that unites professionals and engineers, fostering an environment of collaboration and innovation. In this conference the theme is:

"IGNITING ASEAN'S BLUE ECONOMY AND GREEN ENERGY"

The conference explores various facets of project experience, cutting-edge research and development, and the commercialization of innovative engineering products. Total of 38 papers, each hailing from one of the 8 ASEAN countries are curated. The papers span diverse topics, including Cities and Building, Ecosystem Support, Emissions Reduction, New and Innovative Energy, Transport and Tourism. Notable papers include discussions on the readiness of digital transformation in Brunei Darussalam's green building construction industry, Kuala Lumpur's pioneering Smart City initiatives and carbon emission reduction, ASEAN's potential for sustainable ocean tourism, Assessment Of Horizontal Axis Wind Microturbine and In Myanmar, Towards Sustainable Nuclear Waste Management in Philippines and a comprehensive review of clean energy extraction from sea and saline brines in Indonesia. This book compiles all paper proceedings.

CAFEO 41ST ENGINEERING CONFERENCE 2023

RUNDOWN PAPER PRESENTATION CAFEO 41

NUSA 2, BALI 21-23 NOVEMBER 2023

Tuesday 21 Nov 2023 - 1st Session

No.	Time	Code	Session	Moderator	Paper Title	Presenter
1	08.00 - 08.15	B72	Cities & Building	Prof. Ir. Putu Alit Suthanaya, ST, M.EngSc, Ph.D	INCORPORATING URBAN SUSTAINABILITY PRINCIPLES IN THE DEVELOPMENT OF INDONESIAN NEW CAPITAL NUSANTARA	Naufal Azaki
2	08.15 - 08.30	A16	Cities & Building		EXPLORING THE READINESS OF DIGITAL TRANSFORMATION OR GREEN BUILDING CONSTRUCTION INDUSTRY IN BRUNEI DARUSSALAM	Ir.Chin Lee Tuck
3	08.30 - 08.45	A48	Cities & Building		NUMERICAL MODELING THE EFFECT OF EXTREME TEMPERATURES ON ROOMS WITH MORTAR FOAM WALLS USING LISA V.8 FEA	Ir. Aco Wahyudi Efendi
4	08.45 - 09.00	B75	Cities & Building		DVB-T2 AND DVB-S2 SIMULINK: GREEN MODELS FOR ASEAN ENGINEERS	Jeewa Vengadasalam
5	09.00 - 09.15	B77	Cities & Building		IMPLEMENTATION OF GREEN BUILDING FOR ENERGY SAVINGS POTENTIAL IN NIPAH MALL BUILDING	Muh. Agung Triady Putra
6	09.15 - 09.30	QA				
7	09.30 - 09.45	COFFEE BREAK				
8	09.45 - 10.00	A18	Ecosystem	Prof. Dr.-Ing Ir. Misri Gozan, M.Tech, IPU, ASEAN Eng	ESTIMATION OF BIOMASS CONTENT AND CO2 UPTAKE IN THE MANGROVE FOREST CONSERVATION AREA SERIBU CEMARA BEACH CSR PROGRAM PT PLN (PERSERO) UIP KALBAGBAR	Widyanto Hadi Prasetyo
9	10.00 - 10.15	B74	Ecosystem		TREATMENT OF SULLAGE WATER USING CDS TECHNOLOGY – A CASE STUDY OF TIONGNAM URBAN AREA SULLAGE WATER TREATMENT PLANT	Yale Wong
10	10.15 - 10.30	A58	Ecosystem		PROSPECTS OF LOW HEAD DAM SCHEMES IMPLEMENTATION ALONG AYEYARWADY RIVER	Kyi Thar
11	10.30 - 10.45	A26	Ecosystem		BUILDING BLUE ECONOMY CLUSTERS TOWARDS SUSTAINABLE DEVELOPMENT IN SOUTHEAST ASIA: ECOSYSTEM/S APPROACH WITH SECTORAL SYNERGIES, PATHWAYS, AND CHALLENGES	Nerissa Gatdula
12	10.45 - 11.00	A47	Ecosystem		ESTABLISHING REGIONAL REGULATION TO ENHANCE THE UTILIZATION OF PALM-OIL BASED SUSTAINABLE AVIATION FUEL (SAF) IN ASEAN AVIATION INDUSTRY	Prayitno
13	11.00 - 11.15	QA				
14	11.15 - 11.30	A08	Air & Emission	Prof. Ir. Meilana Dharma Putra, MSc, PhD., IPM.	EMISSION REDUCTION OF TRANSPORTATION SECTOR IN DKI JAKARTA	Dicky Arisikam
15	11.30 - 11.45	A60	Air & Emission		BUILDING A GREENER FUTURE: KUALA LUMPUR'S SMART CITY INITIATIVES AND CARBON EMISSION REDUCTION	Rusnida Talib
16	11.45 - 12.00	A54	Air & Emission		ASSESSMENT OF HORIZONTAL AXIS WIND MICROTURBINE WITH POWER OF 5 KW	Naing Htoo Hlaing
17	12.00 - 12.15	A61	Air & Emission		BALANCING ENERGY CONSUMPTION, ECONOMIC GROWTH, AND EMISSION REDUCTION IN ASEAN NATIONS: INSIGHTS INTO THE GREEN ENERGY TRANSITION	Prof. Romano Q. Neyra, ASEAN Eng.
18	12.15 - 12.30	QA				
19	12.30 - 12.45	LUNCH				
20	12.45 - 13.00					
21	13.00 - 13.15					
22	13.15 - 13.30					
23	13.30 - 13.45	A46	New Energy	Prof. Ir. Seri Maulina M.Si., Ph.D	ERGONOMIC DESIGN AND DEVELOPMENT OF FOOD CART WITH SOLAR PHOTOVOLTAIC SYSTEM	Willie Castillo Buclatin
24	13.45 - 14.00	A67	New Energy		TOWARDS SUSTAINABLE NUCLEAR WASTE MANAGEMENT: A STUDY OF PHILIPPINE GEOLOGICAL DISPOSAL ALTERNATIVES	Dr. King Harold A. Recto, ASEAN Eng., ACPE
25	14.00 - 14.15	A53	New Energy		DESIGN AND CONSTRUCTION OF AUTOMATIC VOLTAGE REGULATOR FOR 1 KW WIND POWER GENERATION	Yin Yin Mya
26	14.15 - 14.30	A07	New Energy		UNLOCKING INDONESIA'S ENERGY POTENTIAL: COMPREHENSIVE REVIEW OF EXTRACTING CLEAN ENERGY FROM SEA AND SALINE BRINES	Rahadian Nopriantoko
27	14.30 - 14.45	A29	Innovative Environment		FIRST GBI GOLD-RATED CONFECTIONERY MANUFACTURING FACILITES IN MALAYSIA	Catherine Siew Ping Sim
28	14.45 - 15.00	QA				
29	15.00 - 15.15	A20	Innovative Environment	Dr. Ir. Soni Solistia Wirawan, M.Eng. IPU	IGNITING ASEAN BLUE ECONOMY THROUGH SUSTAINABLE OCEAN TOURISM	Ir. Vun Wey Tyng
30	15.15 - 15.30	B73	Innovative Environment		FLIPPING THROUGH HISTORY: MALAYSIA'S EXPERIENCE IN SMART PORTS DURING THE COVID-19 PANDEMIC	Syuhaida Ismail
31	15.30 - 15.45	A33	Innovative Environment		GREEN MINE ENERGY RESILIENCE PLAN; THE FUNDAMENTALLY OF NICKEL SMELTER INDUSTRY SUSTAINABLE SCENARIO INTO INTEGRATING BLUE ECONOMICAL INVESTMENT MODEL EFFICIENCY ON COASTAL MINING AREA IN SULAWESI ISLAND	Ir. Rahmat Mualllim
32	15.45 - 16.00	A06	Innovative Environment		REVOLUTIONISING HOUSING CONSTRUCTION IN MALAYSIA: LEVERAGING BUILDING INFORMATION MODELLING FOR SAFE AND AFFORDABLE HOMES	Nur Syafika Artika Rahim
33	16.00 - 16.15	A45	Innovative Environment		SUSTAINABLE INTEGRATION OF BLUE ECONOMY PRINCIPLES IN THE DEVELOPMENT OF INDONESIAN NEW CAPITAL NUSANTARA	Alfa Adib Ash Shiddiqi
34	16.15 - 16.30	QA				
35	16.30 - 16.45	A50	Material	Widyaka Kartanegara, ST, MT	NICKEL INDUSTRIAL DECARBONIZATION PROGRAM STUDY CASE IN SOROWAKO SMELTER	Zainuddin
36	16.45 - 17.00	A82	Energy		Grizzly Reduction Kiln Fatigue Analysis	Asep Suharto
37	17.00 - 17.15	QA				

Thursday 23 Nov 2023 - 2nd Session

	Time	Code	Session	Moderator	Paper Title	Presenter
1	08.00 - 08.15	A63	Ecosystem	Widyaka Kartanegara, ST, MT	STRENGTH CHARACTERISTICS OF FLY ASH BOTTOM ASH WASTE AS A GEOPOLYMER FOR REINFORCEMENT OF EMBANKMENT MATERIALS ON ROAD PAVEMENTS WITH THE ADDITIONAL OF MICROORGANISM	Steeva Rondonuwu
2	08.15 - 08.30	B76	Ecosystem		SURFACE HYDROPHOBIC MODIFICATION OF OPEFB CELLULOSE WITH TRIGLYCERIDES FROM VEGETABLE OILS FOR APPLICATION AS GREEN COATING ADDITIVES OF BUILDING	Ching Yern Chee
3	08.30 - 08.45	B81	Building		IDENTIFICATION OF BARRIERS AND CHALLENGES FACED BY CONTRACTORS IN ENERGY EFFICIENT BUILDING FOR AFFORDABLE HIGH-RISE HOUSING IN MALAYSIA TOWARDS GREEN SUSTAINABLE CONSTRUCTION IN MALAYSIA.	Ms. Ainarull Assikin Abdul Hadi
4	08.45 - 09.00	B79	Building		GREEN IOT: THE ENVIRONMENTAL GAME-CHANGER FOR ENERGY EFFICIENT BUILDING	Ir. Tony Cheng Yew Leong
5	09.00 - 09.15	A43	Building		WHY ARE GREEN BUILDING AS ENERGY EFFICIENT BUILDING IS A MUST? REVIEWING INDONESIA'S RESPONSE	Ngakan Ketut Acwin Dwijendra
6	09.15 - 09.30	**QA**				
7	09.30 - 09.45	**COFFEE BREAK**				
8	09.45 - 10.00	A21	Transport & Tourism	Prof. Ir. Putu Alit Suthanaya, ST, M.EngSc, Ph.D	ENGINEERING PROPERTIES OF SUSTAINABLE GREEN ASPHALT INCORPORATING CRUMB RUBBER USING DRY PROCESS: SABAH, MALAYSIA EXPERIENCE	Nurul Ariqah
9	10.00 - 10.15	A42	Transport & Tourism		MARITIME TRANSPORTATION IN THE CITY OF MANADO	Theo Kurniawan Sendow
10	10.15 - 10.30	B78	Transport & Tourism		FEASIBILITY STUDY OF SOLAR-POWERED ELECTRIC VEHICLE CHARGING INFRASTRUCTURE AT SELECTED PETROL STATIONS IN MALAYSIA	Ir. Dr. Siow Chun Lim
11	10.30 - 10.45	B80	Energy		OCEAN THERMAL ENERGY CONVERSION; POTENTIAL TECHNOLOGY FOR GREEN ENERGY IN ASEAN	Ir. Dr. Harris Abd Rahman Sabri
12	10.45 - 11.00	A28	Building		FIRST DGNB PLATINUM- CERTIFIED FACTORY IN ASIA: A SUSTAINABLE BUILDING DESIGN ACHIEVEMENT ON THE SEMICONDUCTOR FINAL TESTING FACILITY IN BATU KAWAN INDUSTRIAL PARK (BKIP) PENANG, MALAYSIA	Sophia Sheau Wei Than
	11.00 - 11.15	**QA**				
13	11.15 - 11.30	A15	Energy	Dr. Ir. Soni Solistia Wirawan, M.Eng. IPU	PENSTOCK REINFORCEMENT LARONA HYDRO POWER PLANT	Baso Murdin
14	11.30 - 11.45	A83	Energy		Plant Air Compressor Optimization Study Case In Sorowako Smelter	Muh. Amirul Wahyi. C
15	11.45 - 12.15	**QA**				
16	12.15 - 12.30	**END SESSION**				

Paper Proceeding Engineering Conference CAFEO 41					
NUSA 2, BALI 21-23 NOVEMBER 2023					
	Code	**Session**	**Paper Title**	**Author**	**Presenter**
1	B72	Cities & Building	INCORPORATING URBAN SUSTAINABILITY PRINCIPLES IN THE DEVELOPMENT OF INDONESIAN NEW CAPITAL NUSANTARA	Danis H Sumadilaga, Naufal Azaki, Nazib Faizal	Naufal Azaki
2	A16	Cities & Building	EXPLORING THE READINESS OF DIGITAL TRANSFORMATION OR GREEN BUILDING CONSTRUCTION INDUSTRY IN BRUNEI DARUSSALAM	Ir. Chin Lee Tuck, Dr. Chan Sai Keong, Prof. Ir. Dr Tan Chee Fai	Chin Lee Tuck
3	A48	Cities & Building	NUMERICAL MODELING THE EFFECT OF EXTREME TEMPERATURES ON ROOMS WITH MORTAR FOAM WALLS USING LISA V.8 FEA	Aco Wahyudi Efendi, Novia Safitri	Aco Wahyudi Efendi
4	B75	Cities & Building	DVB-T2 AND DVB-S2 SIMULINK: GREEN MODELS FOR ASEAN ENGINEERS	Jeewa Vengadasalam	Jeewa Vengadasalam
5	B77	Cities & Building	IMPLEMENTATION OF GREEN BUILDING FOR ENERGY SAVINGS POTENTIAL IN NIPAH MALL BUILDING	Muh. Agung Triady Putra, Nurul Asmarani	Muh. Agung Triady Putra
6	A18	Ecosystem	ESTIMATION OF BIOMASS CONTENT AND CO2 UPTAKE IN THE MANGROVE FOREST CONSERVATION AREA SERIBU CEMARA BEACH CSR PROGRAM PT PLN (PERSERO) UIP KALBAGBAR	Widyanto Hadi Prasetyo, Pradita Teguh Irawan, Dhio Dwinofiansyah Putra	Widyanto Hadi Prasetyo
7	B74	Ecosystem	TREATMENT OF SULLAGE WATER USING CDS TECHNOLOGY – A CASE STUDY OF TIONGNAM URBAN AREA SULLAGE WATER TREATMENT PLANT	Yale Wong, Chow Hock Lim	Yale Wong
8	A58	Ecosystem	PROSPECTS OF LOW HEAD DAM SCHEMES IMPLEMENTATION ALONG AYEYARWADY RIVER	Kyi Thar	Kyi Thar
10	A47	Ecosystem	ESTABLISHING REGIONAL REGULATION TO ENHANCE THE UTILIZATION OF PALM-OIL BASED SUSTAINABLE AVIATION FUEL (SAF) IN ASEAN AVIATION INDUSTRY	Prayitno, Dimas Ramadhan, Abdillah Fikri	Prayitno
11	A08	Air & Emission	EMISSION REDUCTION OF TRANSPORTATION SECTOR IN DKI JAKARTA	Dicky Arisikam, Shafira Nur Fadhillah	Dicky Arisikam
12	A60	Air & Emission	BUILDING A GREENER FUTURE: KUALA LUMPUR'S SMART CITY INITIATIVES AND CARBON EMISSION REDUCTION	Rusnida Talib, Rahayu Muhammad Taib	Rusnida Talib
13	A54	Air & Emission	ASSESSMENT OF HORIZONTAL AXIS WIND MICROTURBINE WITH POWER OF 5 KW	Naing Htoo Hlaing	Naing Htoo Hlaing
17	A53	New Energy	DESIGN AND CONSTRUCTION OF AUTOMATIC VOLTAGE REGULATOR FOR 1 KW WIND POWER GENERATION	Yin Yin Mya	Yin Yin Mya
18	A07	New Energy	UNLOCKING INDONESIA'S ENERGY POTENTIAL: COMPREHENSIVE REVIEW OF EXTRACTING CLEAN ENERGY FROM SEA AND SALINE BRINES	Rahadian NOPRIANTOKO, Aries Abbas	Rahadian Nopriantoko
19	A20	Innovative Environment	IGNITING ASEAN BLUE ECONOMY THROUGH SUSTAINABLE OCEAN TOURISM	Vun Wey Tyng	Vun Wey Tyng
20	B73	Innovative Environment	FLIPPING THROUGH HISTORY: MALAYSIA'S EXPERIENCE IN SMART PORTS DURING THE COVID-19 PANDEMIC	Mazlinawati Abdul Majid, Syuhaida Ismail	Syuhaida Ismail
21	A33	Innovative Environment	GREEN MINE ENERGY RESILIENCE PLAN; THE FUNDAMENTALLY OF NICKEL SMELTER INDUSTRY SUSTAINABLE SCENARIO INTO INTEGRATING BLUE ECONOMICAL INVESTMENT MODEL EFFICIENCY ON COASTAL MINING AREA IN SULAWESI ISLAND	Rahmat Muallim, Abdul Rahim Syaban, La Ode Bariun, Jamsir, Abu Sofyan Toppo	Rahmat Mualllim
22	A06	Innovative Environment	REVOLUTIONISING HOUSING CONSTRUCTION IN MALAYSIA: LEVERAGING BUILDING INFORMATION MODELLING FOR SAFE AND AFFORDABLE HOMES	Nur Syafika Artika Rahim, Mohammad Hussaini Wahab, Syuhaida Ismail	Nur Syafika Artika Rahim
23	A45	Innovative Environment	SUSTAINABLE INTEGRATION OF BLUE ECONOMY PRINCIPLES IN THE DEVELOPMENT OF INDONESIAN NEW CAPITAL NUSANTARA	Danis H Sumadilaga, Alfa Adib Ash Shiddiqi, Dapot Andri Agustinus	Alfa Adib Ash Shiddiqi
24	A63	Ecosystem	STRENGTH CHARACTERISTICS OF FLY ASH BOTTOM ASH WASTE AS A GEOPOLYMER FOR REINFORCEMENT OF EMBANKMENT MATERIALS ON ROAD PAVEMENTS WITH THE ADDITIONAL OF MICROORGANISM	Dewi Rantung, Oktovian B. A. Sompie, Steeva G. Rondonuwu, Audie Rumayar	Steeva Rondonuwu
25	B76	Ecosystem	SURFACE HYDROPHOBIC MODIFICATION OF OPEFB CELLULOSE WITH TRIGLYCERIDES FROM VEGETABLE OILS FOR APPLICATION AS GREEN COATING ADDITIVES OF BUILDING	Amirul Aiman Mohd A. Ching Yern Chee	Ching Yern Chee
26	B81	Building	IDENTIFICATION OF BARRIERS AND CHALLENGES FACED BY CONTRACTORS IN ENERGY EFFICIENT BUILDING FOR AFFORDABLE HIGH-RISE HOUSING IN MALAYSIA TOWARDS GREEN SUSTAINABLE CONSTRUCTION IN MALAYSIA.	Ainarull Assikin Abdul Hadi	Ainarull Assikin Abdul Hadi
27	B79	Building	GREEN IOT: THE ENVIRONMENTAL GAME-CHANGER FOR ENERGY EFFICIENT BUILDING	Ir. Cheng Yew Leong, Tony	Tony Cheng Yew Leong,
28	A43	Building	WHY ARE GREEN BUILDING AS ENERGY EFFICIENT BUILDING IS A MUST? REVIEWING INDONESIA'S RESPONSE	Ngakan Ketut Acwin Dwijendra, Kadek Diana Harmayani, I Dewa Gede Agung Diasana Putra, Ida Bagus Putu Adnyana, Desak Ayu Krystina Winastri K	Ngakan Ketut Acwin Dwijendra
29	A21	Transport & Tourism	ENGINEERING PROPERTIES OF SUSTAINABLE GREEN ASPHALT INCORPORATING CRUMB RUBBER USING DRY PROCESS: SABAH, MALAYSIA EXPERIENCE	Nurul Ariqah Ispal, Lillian Gungat, Jeffrey Koh, Mohd Ishaq Selamat	Nurul Ariqah
30	A42	Transport & Tourism	MARITIME TRANSPORTATION IN THE CITY OF MANADO	Theo Kurniawan Sendow, Oktovian B. A. Sompie, Lucia I.R. Lefrandt, Audie L. E. Rumayar	Theo Kurniawan Sendow
31	B78	Transport & Tourism	FEASIBILITY STUDY OF SOLAR-POWERED ELECTRIC VEHICLE CHARGING INFRASTRUCTURE AT SELECTED PETROL STATIONS IN MALAYSIA	Siow Chun Lim, Adeesarn Chindamanee	Siow Chun Lim
32	B80	Energy	OCEAN THERMAL ENERGY CONVERSION; POTENTIAL TECHNOLOGY FOR GREEN ENERGY IN ASEAN	Ir Dr Harris Abd Rahman Sabri, Dr Sathiabama T. Thirugnana	Harris Abd Rahman Sabri
33	A29	Innovative Environment	FIRST GBI GOLD-RATED CONFECTIONERY MANUFACTURING FACILITES IN MALAYSIA	Catherine Siew Ping Sim, Zi Xun Ooi, Tze Hoong Ooi, Ji Herng Tang, Yee En Seah	Catherine Siew Ping Sim
34	A28	Building	FIRST DGNB PLATINUM- CERTIFIED FACTORY IN ASIA: A SUSTAINABLE BUILDING DESIGN ACHIEVEMENT ON THE SEMICONDUCTOR FINAL TESTING FACILITY IN BATU KAWAN INDUSTRIAL PARK (BKIP) PENANG, MALAYSIA	Sophia Sheau Wei Than, Chie Tung Lim, Lai Hoong Lee, Wei Huat Khor, Kent Khai Lim, Muhammad Azmin Azizan	Sophia Sheau Wei Than
35	A50	Material	NICKEL INDUSTRIAL DECARBONIZATION PROGRAM STUDY CASE IN SOROWAKO SMELTER	Baso Murdin, Zainuddin, Busyairi, Wahyu Setydjati, Fahmi Izdiharrudin	Zainuddin
36	A82	Energy	GRIZZLY REDUCTION KILN FATIGUE ANALYSIS	Baso Murdin, Asep Suharto, Fahmi Izdiharrudin, Danto Joro1, Muhtar Wahab	Asep Suharto
37	A15	Energy	PENSTOCK REINFORCEMENT LARONA HYDRO POWER PLANT	Baso Murdin, Anom Prasetio, Kiamuddin, Zainuddin, Fahmi Izdiharrudin	Baso Murdin
38	A83	Energy	PLANT AIR COMPRESSOR OPTIMIZATION STUDY CASE IN SOROWAKO SMELTER	Baso Murdin, Muh. Amirul Wahyi C., Danto Joro, Fahmi Izdiharrudin, Rismal Muchtar	Muh. Amirul Wahyi. C

Table of Contents

Paper Proceeding Engineering Conference CAFEO 41

UNLOCKING INDONESIA'S ENERGY POTENTIAL: EXTRACTING CLEAN ENERGY FROM SEA AND SALINE BRINES

Rahadian NOPRIANTOKO[1], Aries Abbas[2]

[1]Mechanical Engineering Department, Engineering Faculty, Universitas Krisnadwipayana, Bekasi 13077, Indonesia.
[2]Persatuan Insinyur Indonesia (PII), Jakarta, 12980, Indonesia

rahadiann@unkris.ac.id

Abstract

The potential of Energy extraction from seawater and saline brines holds the potential to transform Indonesia's energy landscape. This paper presents a comprehensive review of the technologies and opportunities in this field within the Indonesian context. The analysis encompasses methods such as pressure-retarded osmosis, reverse osmosis, and electrodialysis, harnessing the salinity gradient between seawater and saline brines to produce clean, renewable energy. A quantitative assessment of Indonesia's sea and saline brine resources unveils an abundant, yet largely untapped, renewable energy source. With a coastline stretching over 108,000 kilometers and vast maritime territory, Indonesia can potentially harness approximately 1.4 billion cubic meters of seawater daily. The paper delves into the significant challenges and constraints that currently impede the widespread implementation of these technologies in Indonesia. Environmental considerations, encompassing potential impacts on marine ecosystems, alongside economic feasibility assessments, highlight the multifaceted complexities associated with adopting these novel approaches. The findings underscore the urgent need for a robust framework that supports research, encourages innovation, and guides policy development to effectively integrate energy extraction from sea and saline brines into Indonesia's energy sector. A crucial emphasis is placed on the necessity of collaboration among academia, industry, and government entities. This collaboration is fundamental in advancing technology development, optimizing energy conversion processes, and proactively mitigating potential environmental impacts. In conclusion, this review provides quantitative insights into the directions for future research that are essential to unlock the full potential of energy extraction from sea and saline brines. These avenues encompass the exploration of hybrid systems aiming for up to 30% enhanced efficiency, coupled with improvements of up to 15% in energy conversion efficiencies, and the investigation of novel materials and technologies. Moreover, the successful harnessing of energy from sea and saline brines is projected to make a significant contribution to Indonesia's energy transition objectives, potentially accounting for up to 10% of the nation's electricity demand by 2030. This quantifiable progress has the potential to enhance energy security, significantly reduce greenhouse gas emissions by up to 1.5 million tons annually, and authentically advance sustainable development. These achievements align harmoniously with Indonesia's commitments under the Paris Agreement.

Keywords: energy extraction, Indonesia, green energy, renewable technology, sustainability

1. Introduction

Indonesia, with its vast archipelago and burgeoning population, finds itself at a crucial juncture in addressing its ever-expanding energy requirements. This section elucidates the pressing energy needs of the nation, which have been propelled by factors like population growth and economic development. Indonesia, as the world's fourth most populous nation, is grappling with an exponential increase in energy consumption. Its diverse and dynamic economy, coupled with a population exceeding 270 million [1], underscores the critical role that energy plays in driving progress and development across the nation. The demand for energy, in various forms, has reached unprecedented levels, from electricity to transportation fuels. Indonesia's energy needs have been significantly amplified by its rapid population growth and urbanization. Over the past few decades, the nation has witnessed an extraordinary surge in its urban centers. Millions of Indonesians have transitioned from rural to urban life, a shift that has necessitated substantial energy investments to power homes, industries, and transportation networks in these burgeoning cities.

Indonesia's economic growth, particularly in manufacturing and industry, has led to a rising demand for energy. To address this, the country is pursuing a strategy that combines fossil fuels with renewable and alternative energy sources to ensure a sustainable and secure energy future. Challenges include extending energy access to remote regions, modernizing infrastructure, and integrating renewable resources. Indonesia also faces environmental challenges due to coal reliance and deforestation for energy. Balancing economic feasibility with sustainability is complex. Regulatory frameworks must incentivize clean energy investments and sustainable practices while reducing greenhouse gas emissions. To address these challenges, Indonesia is exploring energy extraction from sea and saline brines, leveraging its extensive coastlines. This approach offers a clean and renewable energy source, though it requires addressing environmental concerns, economic viability, and policy collaboration. Diversifying energy sources is essential for

Indonesia's long-term energy security and environmental responsibility, aligning with its developmental goals and commitment to reducing its carbon footprint. Sea and saline brine energy can meet current and future energy needs without emitting greenhouse gases, contributing to climate change mitigation.

Innovation and technology are the engines of progress. As the world advances, new technological frontiers emerge. The energy extraction from sea and saline brines leverages cutting-edge technologies like pressure-retarded osmosis, reverse osmosis, and electrodialysis. Exploring energy extraction from sea and saline brines in Indonesia offers cleaner energy, promotes research and development, and drives economic growth. It positions Indonesia as an innovative player in sustainable energy, potentially leading to technology exports and collaborations. Reduced energy imports enhance national sovereignty and economic stability, reducing vulnerability to global energy market fluctuations. This move towards energy independence aligns with Indonesia's economic goals, environmental responsibilities, and technological ambitions. It offers a unique opportunity to diversify the energy mix, meet growing demand, reduce carbon emissions, and promote sustainability.

Indonesia, a country in Southeast Asia, is experiencing significant economic growth and population expansion, leading to a substantial increase in energy demand. The energy infrastructure struggles to keep up, resulting in power shortages and environmental concerns due to heavy reliance on fossil fuels. Exploring energy extraction from seawater and saline brines is seen as a compelling solution, utilizing the country's extensive coastlines and maritime territory to tap into clean and renewable energy sources. This approach aligns with the need to diversify the energy mix, enhance energy security, and reduce the environmental footprint. The primary objective of this paper is to comprehensively review the technologies and opportunities related to extracting energy from seawater and saline brines in Indonesia. The research aims to clarify the technology's complexities, assess resource abundance and accessibility, identify key challenges, and stress the importance of collaboration among academia, industry, and government entities. The research also outlines future directions and areas for further exploration, including hybrid systems, energy efficiency improvements, and innovative materials and technologies. The paper aims to provide valuable insights, quantitative data, and a roadmap to support Indonesia's transition to a sustainable energy future, aligning with international commitments under the Paris Agreement [2] and addressing economic, environmental, and energy security concerns.

2. Materials and Methods

In order to comprehensively explore the potential of extracting energy from seawater and saline brines in the Indonesian context, a systematic research approach was employed. This approach encompassed multiple stages, each designed to provide a detailed and rigorous assessment of the technologies involved. The research commenced with an extensive literature review. This phase involved the identification and review of academic papers, reports, and publications from reputable sources such as academic databases, government publications, and international organizations. The purpose was to establish a robust understanding of the various technologies available for energy extraction from seawater and saline brines. Subsequently, a comprehensive evaluation of these technologies was conducted. This involved a detailed analysis of their principles, mechanisms, efficiency, and suitability within the Indonesian context. The technologies under scrutiny included pressure-retarded osmosis, reverse osmosis, and electrodialysis. Their comparative advantages, disadvantages, and scalability [3]–[5] were examined to determine their potential applicability to Indonesia's specific conditions. A significant aspect of this research was the quantitative analysis of Indonesia's sea and saline brine resources. This step aimed to provide precise figures regarding the abundance and accessibility of these resources. Accurate data on Indonesia's extensive coastline, maritime territory, and salinity gradients were collected and analyzed to quantify the nation's potential for renewable energy extraction. In the process of this research, a variety of resources were utilized. Access to academic databases, research articles, and reports provided a foundation for understanding the technological landscape. Collaboration with experts in the field, both nationally and internationally, facilitated insights into the practical aspects of energy extraction from seawater and saline brines.

The research followed a systematic approach that involved multiple stages to comprehensively evaluate the subject matter. This method allowed for the identification of viable technologies, a quantified assessment of Indonesia's resource potential, and a thorough understanding of the challenges and opportunities in implementing these technologies in the country. The goal was to provide a foundation for informed decision-making and policy development in the pursuit of sustainable and clean energy sources for Indonesia. To achieve this, a diverse range of resources was leveraged, including scholarly journals, research papers, official publications, and reports from government agencies. Industry reports, case studies, collaborations with academic institutions and research centers, as well as interviews with subject matter experts, enriched the research with practical insights and expert opinions. Drawing parallels with international cases and best practices further enriched the analysis. This comprehensive approach facilitated a quantitative review of energy extraction technologies from seawater and saline brines. It ensures that the findings are grounded in empirical data and expert knowledge, serving as a valuable resource for policymakers, researchers, and stakeholders. The systematic methodology supports informed decision-making and policy formulation for sustainable, clean energy sources in Indonesia. The methodical procedure guarantees the dependability and pertinence of the information conveyed, enabling readers to acquire an all-encompassing comprehension of the topic. In conclusion, the outcomes and discussions lead to drawing deductions. Generally, the research's sequence is visually represented in Figure 1.

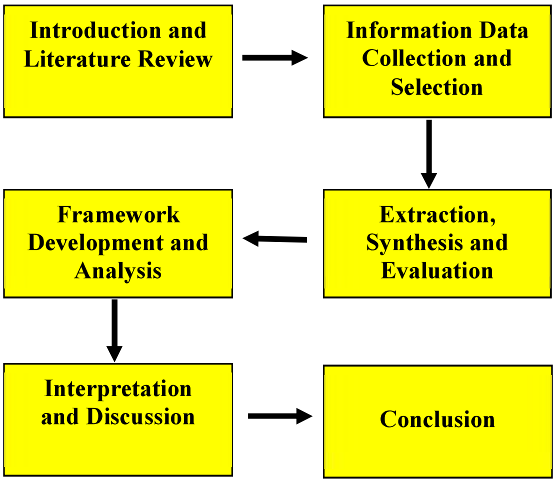

Figure 1. Flowchart of Methodology

3. Results and Discussion

3.1. Energy Extraction Technologies

Pressure-Retarded Osmosis (PRO) is an innovative technology that utilizes the osmotic pressure difference between seawater and fresh water (or low-salinity water) to generate clean and sustainable energy [6], the system diagram is given by Figure 2. In PRO, two separate solutions are involved: a "draw" solution with high salinity and a "feed" solution with low salinity. These solutions are placed on either side of a semipermeable membrane, which selectively allows water molecules to pass through but not the dissolved salts. This migration of water molecules causes an increase in the volume and pressure of the draw solution, creating hydraulic pressure. The generated hydraulic pressure can then be used to drive a hydraulic turbine or a pressure exchange device, which in turn drives a generator to produce electricity. Pressure-Retarded Osmosis (PRO) is a promising technology that leverages the osmotic pressure difference between seawater and low-salinity water to generate clean and sustainable energy. The abundance of seawater resources and the availability of low-salinity water sources, such as rivers or brackish water, offer an excellent opportunity to harness this technology for clean energy production [4]. Its application in Indonesia can tap into the nation's abundant seawater resources and contribute to its energy transition goals, enhancing energy security while minimizing environmental impacts.

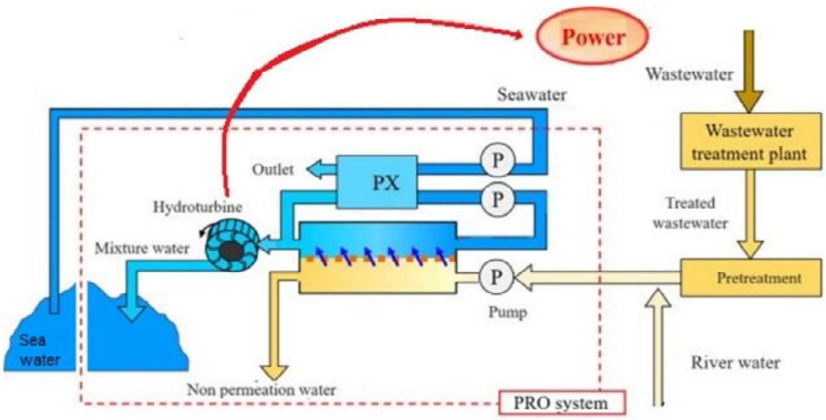

Figure 2. System Diagram of Pressure-Retarded Osmosis (PRO) Technology

Reverse Osmosis (RO) is a well-established technology primarily known for desalinating saline water to produce freshwater [7]–[11], the system diagram is shown by Figure 3. However, it can also be ingeniously adapted to harness osmotic pressure as a potential energy source while simultaneously obtaining freshwater, making it a versatile solution for addressing both water and energy challenges. In PRO, freshwater and draw solution (a solution with higher salinity) are separated by a semipermeable membrane, similar to traditional RO. Essentially, PRO combines the benefits of desalination with the generation of clean and renewable energy, making it a sustainable and innovative solution. In the context of Indonesia, where both freshwater scarcity and renewable energy generation are significant concerns, RO and its variant PRO hold promise. Reverse Osmosis (RO) and its derivative, Pressure-Retarded Osmosis (PRO), offer a dual-purpose solution for obtaining freshwater from saline water while harnessing osmotic pressure as an energy source. These technologies have the potential to address Indonesia's water and energy challenges, especially in regions with limited freshwater resources and high salinity gradients.

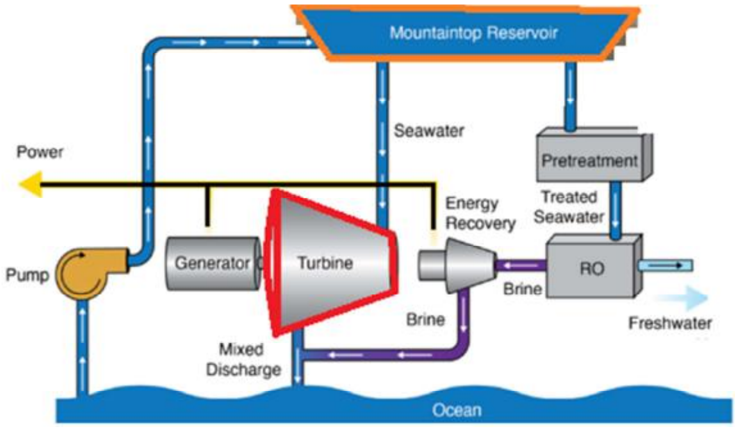

Figure 3. System Diagram of Reserve Osmosis (RO)Technology

Electrodialysis is an innovative technology that uses ion-selective membranes to separate and manipulate ions in aqueous solutions, including seawater and saline brines [12]–[16], as shown in Figure 4. It desalinates water and produces electricity by selectively transporting ions through membranes. Electrodialysis offers a dual solution for Indonesia, addressing freshwater needs and contributing to clean energy goals [17]–[20]. Hybrid systems, combining technologies like PRO, RO, and Electrodialysis, enhance energy efficiency and production. These systems can store excess energy and address Indonesia's intermittent renewable energy challenges [21], [22]. By integrating these technologies, we optimize energy generation and mineral recovery, contributing to sustainable development. Hybrid systems offer a promising approach to tackle Indonesia's complex energy and freshwater challenges by maximizing energy efficiency and addressing intermittency issues.

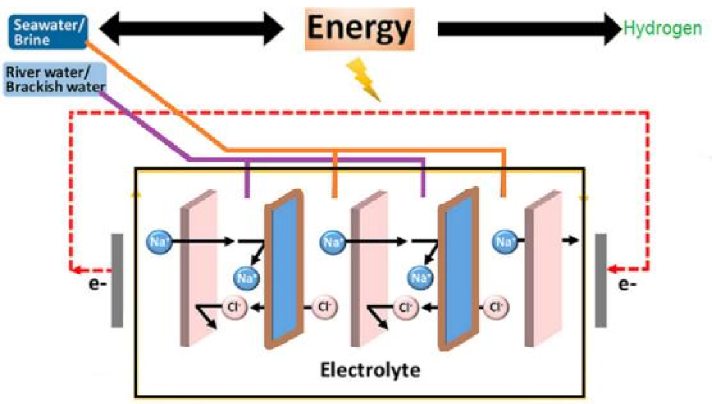

Figure 4. System Diagram of Electrodialysis Technology

3.2. Seawater and Saline Brine Resources in Indonesia

Indonesia, the world's largest archipelagic nation, comprises 17,504 islands and boasts a coastline stretching approximately 108,000 kilometers based on data of Indonesian Navy's Hydro-Oceanographic Center (PUSHIDROSAL), and with vast maritime territory, Indonesia can potentially harness approximately 1.4 billion cubic meters of seawater daily. This unique geographical feature renders Indonesia's maritime territory even more expansive than its land area. Indonesia's total maritime expanse covers about 6.4 million square kilometers, surpassing its land area of 1.9 million square kilometers [23]. Indonesia's geographical features, including its vast coastline and maritime territory, provide a significant opportunity for harnessing seawater and saline brine resources as a renewable energy source. With hundreds of thousands of kilometers of coastline and a wealth of seawater and saline brines, Indonesia possesses an untapped reserve for clean energy production. This geographical advantage, coupled with its archipelagic configuration, offers a unique platform for integrating innovative technologies into the national energy infrastructure.

Indonesia's tropical climate, with abundant seawater and salinity gradients in coastal areas, offers a valuable resource for energy generation while aligning with sustainability goals. These advantages support the reduction of fossil fuel dependence, greenhouse gas emissions mitigation, energy security, and economic growth. Accessing these resources, particularly in developed coastal areas with seaports, is relatively straightforward. However, challenges exist in remote or less-developed regions, necessitating infrastructure development and logistics improvements. Environmental considerations are crucial in responsible energy extraction. Safeguards and regulations are vital to protect marine ecosystems. Efforts to improve accessibility should ensure equitable benefits distribution across diverse regions, addressing infrastructure and transportation challenges. Balancing economic development with environmental sustainability is essential. Quantitative assessments of Indonesia's seawater and saline brine resources emphasize their vast potential for clean and renewable energy. Innovative technologies like PRO, RO, and ED can harness the salinity gradient, contributing significantly to Indonesia's power grid. Additionally, saline brines offer energy potential that enhances energy security and aligns with global emissions reduction efforts. The research explores the environmental impact and strategies for mitigation, ensuring Indonesia's commitment to sustainable development. These resources provide a unique opportunity to meet energy needs while promoting a cleaner and more sustainable future, benefiting Indonesia's energy landscape. The research aims to provide detailed insights into this potential, facilitating innovative solutions.

The successful extraction of energy from seawater and saline brines in Indonesia carries the promise of transformative impacts that extend across various critical dimensions. Quantifying these impacts sheds light on the significance of this innovative approach in advancing the nation's energy transition objectives, reducing greenhouse gas emissions, and promoting sustainable development [24]. Indonesia is dedicated to transitioning to a cleaner and more sustainable energy landscape, and the successful extraction of energy from seawater and saline brines is seen as a pivotal step in achieving this goal. By potentially meeting up to 10% of the nation's electricity demand by 2030, this renewable energy source significantly contributes to diversifying the energy mix, enhancing energy security, and reducing dependence on fossil fuels. This shift is essential as Indonesia's traditional reliance on fossil fuels has led to high greenhouse gas emissions. Transitioning to cleaner energy sources is crucial for mitigating climate change. Energy extraction from seawater and saline brines can substantially reduce greenhouse gas emissions, potentially by up to 1.5 million tons annually. This quantifiable reduction underscores Indonesia's commitment to the Paris Agreement and its role in global climate action.

Sustainable development is a top priority for Indonesia, encompassing economic growth, environmental conservation, and social well-being. Extracting energy from seawater and saline brines aligns with sustainability principles by providing a clean and renewable energy source that promotes economic growth, energy access, and environmental protection. It also fosters research, innovation, and the development of a knowledge-based economy. Moreover, it positively impacts marine ecosystems, reduces air pollution, and enhances public health and societal well-being. Quantifying the impact of successful energy extraction from seawater and saline brines underscores its vital role in Indonesia's journey toward a sustainable and low-carbon future. This innovative approach aligns seamlessly with the nation's energy transition goals, greenhouse gas emissions reduction targets, and broader sustainable development objectives. By harnessing the vast potential of this renewable energy source, Indonesia not only secures its energy future but also makes significant strides in environmental stewardship and global climate leadership. The efforts to harness energy from seawater and saline brines in Indonesia align with the nation's commitments under the Paris Agreement, which aims to limit global warming and reduce the impacts of climate change.

At the heart of the Paris Agreement is the goal to reduce greenhouse gas emissions, a major driver of climate change [25]. Energy generation from conventional fossil fuels is a significant source of these emissions. By transitioning towards energy sources like seawater and saline brines, which produce little to no greenhouse gas emissions during electricity generation [11], [26], Indonesia contributes directly to the overarching aim of the Paris Agreement. Energy extraction from seawater and saline brines aligns with the principles of the Paris Agreement, which emphasizes the importance of sustainable development that balances environmental protection with societal needs. This renewable energy source represents a clean and sustainable energy solution that fosters economic growth, ensures energy access, and minimizes environmental harm. The Paris Agreement also stresses the need to build resilience to climate change impacts. Indonesia's pursuit of renewable energy sources like seawater and saline brine energy contributes to resilience by diversifying the energy mix, reducing reliance on fossil fuels susceptible to price fluctuations and supply disruptions. This enhances energy security, making Indonesia better prepared to address climate-related challenges. As a signatory to the Paris Agreement, Indonesia's exploration of energy extraction from seawater and saline brines showcases its commitment to the agreement's goals. It demonstrates international leadership and a dedication to collective climate action, aligning with the spirit of cooperation and solidarity embedded in the Paris Agreement. Indonesia's efforts in this regard contribute significantly to the global fight against climate change and the pursuit of a more sustainable future for all.

3.3. Challenges and Constraints

While the potential of extracting energy from sea and saline brines in Indonesia is undeniably promising, it is not without its share of challenges. Understanding and addressing these challenges is crucial to pave the way for the successful implementation of this innovative technology. One of the foremost challenges is the potential impact on marine ecosystems. The extraction of energy from seawater and saline brines requires the manipulation of salinity gradients, which could have ecological consequences [27]–[29]. Balancing the benefits of clean energy generation with the preservation of marine environments is a complex issue that demands careful consideration when it comes to extracting energy from seawater and saline brines. To ensure minimal harm to marine ecosystems, it's crucial to integrate environmental impact assessments and mitigation strategies into the deployment of these technologies.

Implementing technologies for energy extraction from seawater and saline brines in Indonesia faces significant challenges. Economic feasibility is a major concern, given the substantial initial and operational costs. Assessing cost-effectiveness compared to existing energy sources is crucial, including long-term benefits and infrastructure considerations. Establishing favorable regulatory frameworks is essential to support the widespread adoption of these technologies, covering permitting, environmental regulations, and incentives. Scaling up from small experiments to large-scale applications requires substantial investments and development efforts to optimize efficiency and integration into the energy grid. Public awareness and acceptance are vital, necessitating efforts to build trust and understanding among various stakeholders and local communities. International collaboration can provide expertise, funding, and knowledge exchange but involves complex agreements and negotiations. Addressing these challenges in the development and implementation of energy extraction from seawater and saline brines is crucial to unlock the full potential of this renewable energy source while ensuring economic viability and a sustainable energy future. It is also essential to address environmental considerations for responsible and sustainable practices.

One of the foremost concerns in extracting energy from seawater and saline brines is the potential impact on marine ecosystems [8]. The discharge of highly concentrated brine back into the ocean can alter local salinity levels, affecting marine life and habitats. To mitigate this, careful monitoring of discharge locations, dilution strategies, and the use of diffusers can help disperse brine more effectively, reducing its immediate impact. Increased salinity due to brine discharge can harm aquatic biodiversity, particularly sensitive species. Implementing marine protected areas and conducting regular biodiversity assessments can aid in safeguarding vulnerable ecosystems. Additionally, the development of advanced brine treatment technologies, such as reverse osmosis, can significantly reduce brine salinity before discharge. Discharging brine with high salinity can negatively impact water quality, affecting local communities and industries reliant on coastal waters. To address this, environmental impact assessments should be carried out to determine the potential consequences of brine discharge on water quality. Furthermore, investing in advanced treatment methods to reduce brine salinity can help maintain acceptable water quality standards.

The energy-intensive nature of desalination technologies used in seawater and saline brine energy extraction can inadvertently contribute to greenhouse gas emissions if not powered by renewable sources. A strategic approach involves integrating renewable energy systems, such as solar or wind power, to minimize the carbon footprint associated with energy extraction. Sustainable resource management is essential to ensure the long-term viability of energy extraction from seawater and saline brines. Implementing resource allocation plans and monitoring resource usage can prevent overexploitation and protect these valuable resources. The treatment of brine and other waste products is a critical aspect of mitigating environmental impacts. Advanced treatment methods should be employed to minimize the environmental footprint of waste disposal. Recycling and reusing treated brine can also reduce waste generation. The construction and operation of energy extraction facilities along coastlines can lead to coastal erosion and instability [30], [31]. Mitigating the environmental effects of energy extraction from seawater and saline brines in Indonesia requires the implementation of engineering solutions such as coastal protection structures and sustainable coastal management practices. These measures can help preserve the integrity of coastal environments and minimize adverse impacts. Additionally, engaging local communities and stakeholders is crucial to ensure responsible environmental practices. Public awareness campaigns and community involvement can foster a sense of ownership over environmental protection efforts, leading to more sustainable outcomes.

Addressing environmental factors is pivotal in the successful and responsible implementation of energy extraction from seawater and saline brines in Indonesia. A holistic approach that combines advanced technologies, environmental impact assessments, and sustainable practices can help strike a balance between meeting energy needs and preserving the invaluable marine and coastal ecosystems of the nation. When considering the economic feasibility of energy extraction from seawater and saline brines, it's essential to analyze investment requirements, operational costs, and the potential returns on investment for these technologies. The initial investments in infrastructure, equipment, and research and development are substantial but necessary to establish the facilities and develop innovative solutions for efficient energy conversion. Public-private partnerships and government incentives can help attract the required funding for these capital-intensive projects. Operational costs represent a significant ongoing economic factor, encompassing maintenance, energy consumption, labor, and monitoring expenses. Analyzing these costs is vital to ensure the technology remains financially sustainable over the long term. Implementing energy-efficient equipment and streamlined operational processes can help manage and potentially reduce these costs, improving the overall economic feasibility of these technologies.

The economic viability of energy extraction from seawater and saline brines is closely tied to energy pricing and tariffs [27], [32]. The economic feasibility of energy extraction from seawater and saline brines is influenced by various factors, including market conditions, government policies, and scalability. Market conditions can fluctuate, and government incentives can enhance the technology's attractiveness by providing favorable pricing structures and incentives for clean energy sources. Scalability is crucial for economic feasibility, as increasing the scale of operations can lead to reduced costs per unit of energy produced, emphasizing the importance of efficient system design for scalability. Assessing potential returns on investment (ROI) is fundamental, considering energy production rates, pricing, and operational costs. Despite substantial initial investments, long-term economic benefits, such as revenue generation and energy savings, can make these technologies financially viable.

Government policies and incentives, including tax incentives, subsidies, and feed-in tariffs, play a pivotal role in determining economic feasibility. Policy stability and regulatory support are essential for attracting private sector investments. Technological advancements can significantly impact economic feasibility, with continuous research and development efforts leading to more efficient and cost-effective systems. Material design and system integration improvements can enhance overall economic performance. A comprehensive cost-benefit analysis is valuable for weighing costs against benefits, including energy generation, reduced emissions, and potential revenue streams. Collaborative efforts among governments, industry stakeholders, and research institutions are crucial to address these economic aspects and make clean energy technologies economically viable and sustainable in the Indonesian context.

The successful implementation of energy extraction technologies from seawater and saline brines in Indonesia is significantly influenced by the existing regulatory framework. Regulatory aspects play a crucial role in shaping the development and adoption of these technologies. Environmental regulations ensure compliance with stringent standards to protect marine ecosystems, water quality, and aquatic life. Acquiring licenses and permits is essential for legal and responsible project deployment. Indonesia's energy sector is subject to specific regulations and policies, influencing the integration of new technologies. Existing regulations regarding energy production, distribution, and pricing can impact the economic viability of energy extracted from seawater and saline brines, requiring adjustments to align with national energy transition goals. Intellectual property and technology transfer regulations can either foster or hinder technology development and deployment, making clear guidelines for technology transfer and intellectual property rights essential for innovation and collaboration. Trade regulations and tariffs may also be a consideration if components or materials used in these technologies are imported, necessitating an understanding and navigation of trade regulations for efficient project implementation.

Governments often use incentives and subsidies to promote the adoption of clean energy technologies. Regulations that provide tax incentives, feed-in tariffs, or subsidies for renewable energy projects can significantly boost the economic feasibility of energy extraction from seawater and saline brines [10], [33]–[35]. Regulatory stability and consistency are vital for attracting investments and fostering long-term commitment to these technologies. Frequent regulatory changes or policy uncertainties can deter investors and slow down technology development. Therefore, a predictable and supportive regulatory environment is critical. Regulatory frameworks that encourage collaboration between academia, industry, and government entities can expedite technology development. These frameworks can facilitate research partnerships, technology demonstrations, and shared resources, streamlining the path to commercialization. Navigating the regulatory landscape is a fundamental aspect of deploying energy extraction technologies from seawater and saline brines in Indonesia. A well-structured regulatory framework, one that balances environmental protection, economic feasibility, and technology advancement, can foster the successful integration of these clean energy solutions into Indonesia's energy landscape. Collaborative efforts among stakeholders, clear guidelines, and regulatory adaptability are key to overcoming regulatory challenges and achieving sustainable energy development.

3.4. Collaboration and Policies

among academia, industry, and government is essential for advancing the development and implementation of energy extraction technologies from seawater and saline brines in Indonesia. Each of these stakeholders has a unique role to play in overcoming the challenges and accelerating progress in this field. Academic institutions are hubs of research and innovation, contributing to fundamental research and educating a skilled workforce. They serve as a bridge between theoretical knowledge and practical application, working closely with industry and government. The industry is responsible for scaling up these technologies, turning innovative concepts into tangible solutions. They invest in research and development, undertake pilot projects, and leverage scientific knowledge to make these technologies practical and cost-effective. Government plays a critical role in shaping policies, providing regulatory frameworks, and offering incentives for clean energy technology development. They also establish environmental standards to ensure the sustainability of energy extraction processes. Collaboration ensures that research findings are translated into practical applications, technologies are optimized for efficiency and cost-effectiveness, and ethical and environmental considerations are integrated into the development process. It fosters an environment of innovation, knowledge sharing, and continuous improvement. This synergy among academia, industry, and government holds the potential to drive significant advancements in technology development and energy conversion optimization, positioning Indonesia on the path to a cleaner and more secure energy future.

In the journey towards harnessing the potential of energy extraction from seawater and saline brines in Indonesia, the role of well-crafted policies cannot be overstated. Policies act as the bedrock upon which technological innovation and sustainable energy practices are built. Their development is essential to foster an enabling environment that encourages investment and adoption of cutting-edge technologies [36]–[38]. Policies that align with Indonesia's energy transition objectives are crucial for the development of energy extraction from seawater and saline brines. These policies should stimulate innovation and incentivize research and development (R&D) activities in the field. Incentives like tax credits, grants, and subsidies can encourage academia and industry to invest in advancing existing technologies or creating new ones. These incentives attract both domestic and international investments, positioning Indonesia as an attractive destination for collaboration.

Clear and comprehensive regulatory frameworks are indispensable to ensure that energy extraction processes adhere to environmental standards and safety protocols. These regulations provide guidelines on resource utilization, waste management, and ecosystem protection, instilling investor confidence by minimizing uncertainties regarding compliance and permits. To address ecological impacts, policies must prioritize environmental protection. Legislation should mandate comprehensive environmental impact assessments and adherence to sustainable practices. Incentives can be provided for the development and implementation of advanced, eco-friendly technologies. Policies should also encourage collaborative initiatives among academia, industry, and government through research and development centers, partnerships, and funding programs, fostering cross-sectoral knowledge exchange and collective problem-solving.

Indonesia should establish a clear energy transition roadmap that outlines the role of energy extraction from seawater and saline brines in its broader energy mix. This roadmap serves as a strategic guide for policymakers, investors, and industry players, aligning efforts toward sustainability and energy security goals. Transparent governance mechanisms are essential to ensure effective and fair policy implementation. Regular audits and assessments can monitor policy outcomes and hold stakeholders accountable for their contributions to the energy transition agenda. Well-crafted policies are instrumental in shaping the trajectory of energy extraction from seawater and saline brines in Indonesia, providing the necessary framework for innovation, investment, and sustainable practices. By aligning policies with Indonesia's energy transition objectives, the nation can unlock its full potential in clean and renewable energy, significantly contributing to a more sustainable and resilient future.

3.5. Future Directions and Further Research

As we look ahead, it is crucial to identify the research directions that must be pursued to unlock the full potential of energy extraction from seawater and saline brines in Indonesia. These future directions encompass a range of innovations and strategies aimed at maximizing the benefits of this sustainable energy source. One promising avenue is the exploration of hybrid systems that combine multiple energy extraction technologies [39], [40]. Integrating various technologies like pressure-retarded osmosis, reverse osmosis, and electrodialysis can boost energy efficiency when extracting energy from seawater and saline brines. To achieve this, research should focus on improved membrane materials and system designs, with a goal of achieving up to 30% higher efficiency. Exploring advanced materials and minimizing environmental impacts is essential. It's important to ensure economic viability through innovative financing and regulatory frameworks. Large-scale pilot projects and community engagement are key to showcasing the practical application of energy extraction systems. In Indonesia, advanced hybrid systems that combine different technologies and energy sources, such as PRO and Electrodialysis, offer a promising approach to enhance energy generation from seawater and saline brines. Additionally, integrating renewable sources like solar panels, wind turbines, and tidal energy generators can maintain a consistent energy supply, increasing overall system efficiency and meeting the country's growing energy demands. These efforts can solidify Indonesia's leadership in renewable energy innovation.

The integration of multiple technologies can also lead to more environmentally friendly energy extraction. By maximizing efficiency, less energy goes to waste, reducing the environmental footprint associated with energy production [41]–[43]. Developing advanced hybrid systems is not without challenges. It requires sophisticated control systems, engineering expertise, and investment. Additionally, the integration of multiple technologies may introduce complexity into operations and maintenance. In Indonesia's journey toward a sustainable energy future, advanced hybrid systems hold immense potential. By merging various technologies and energy sources, these systems can maximize efficiency, increase energy output, and reduce environmental impact. They represent a critical step forward in achieving Indonesia's energy transition goals, enhancing energy security, and contributing to a cleaner, more sustainable future. Collaboration among academia, industry, and government entities will be essential in advancing the research, development, and deployment of these advanced hybrid systems.

The future of energy extraction from seawater and saline brines in Indonesia hinges on embracing critical steps that can significantly enhance the effectiveness and sustainability of this innovative approach. Among these steps, the implementation of hybrid systems, the pursuit of improved energy efficiency, and the development of novel materials stand out as crucial pathways forward. Integrating multiple energy extraction technologies into hybrid systems holds immense promise. By combining methods such as pressure-retarded osmosis, reverse osmosis, and electrodialysis, we can achieve synergistic effects that substantially increase overall efficiency and energy output. Hybrid systems represent a critical step towards optimizing energy extraction processes [40], [44], making them more reliable and cost-effective. One of the key challenges in energy extraction from seawater and saline brines is achieving higher energy conversion efficiency. This necessitates research and development efforts aimed at refining membrane materials, system designs, and energy conversion processes. Improved efficiency, with the potential to enhance it by up to 30%, can make energy extraction from these sources economically competitive and environmentally sustainable.

The focus on innovative materials tailored for energy extraction components is crucial for technological progress. These materials can enhance efficiency and durability, adapting to different conditions. Hybrid systems combining various technologies increase energy yield and reduce costs, making energy extraction economically viable and environmentally friendly. These advancements align with Indonesia's commitment to sustainable energy and environmental goals. Efficiency is vital in utilizing salinity gradients for electricity generation. Technologies like Pressure-Retarded Osmosis, Reverse Osmosis, and Electrodialysis tap into osmotic pressure and ion differences. However, improving energy conversion efficiency is a challenge, as traditional systems suffer from losses during energy transfer and conversion. Membrane technology plays a pivotal role in many salinity gradient energy conversion processes. Enhancements in membrane materials and designs are essential for improving efficiency [45]. Researchers are focusing on developing advanced membranes that allow for faster ion transport while maintaining selectivity [46], [47]. This translates to higher power output per unit of membrane area.

Efficiency in energy conversion systems is essential. Engineers are working on innovative system designs, flow patterns, and component adjustments to maximize mass transfer and minimize energy losses. PRO technology is being improved with a focus on better membranes, operating conditions, and reducing fouling. Energy recovery devices are also being developed to capture and reuse wasted energy, further boosting overall conversion efficiency. As mentioned in previous discussions, hybrid systems that combine multiple technologies also play a role in enhancing efficiency [17]. By integrating different energy conversion mechanisms, these systems can capture a broader spectrum of energy from salinity gradients, leading to greater overall efficiency. Real-time monitoring and control systems are vital for optimizing energy conversion efficiency. These systems allow for adjustments based on changing conditions, ensuring that the process operates at peak performance. Efficiently converting salinity gradients into electricity is crucial for Indonesia's sustainable energy goals. Improvements in membrane technology, system design, energy recovery, and hybrid systems enhance efficiency. Collaboration among stakeholders is essential. The use of novel materials and cutting-edge technologies can further boost energy extraction from salinity gradients, fostering innovation and progress in renewable energy.

Membranes are fundamental in many salinity gradient energy conversion technologies, such as Reverse Osmosis (RO) and Pressure-Retarded Osmosis (PRO) [19], [48], [49]. Researchers are actively working on creating advanced membranes that are more selective, robust, and efficient. These membranes can improve the overall performance of energy conversion systems. Nanotechnology holds promise in enhancing the properties of membranes and other components used in salinity gradient energy extraction. Nanomaterials can facilitate faster ion transport, reduce fouling, and increase energy conversion rates. The development of conductive materials is essential for improving the efficiency of electrodialysis-based systems. Enhanced ion conductivity can lead to better energy conversion and reduced energy losses. Environmental considerations are crucial. Innovations are focused on eco-friendly materials that minimize the environmental footprint of energy extraction processes. Sustainable materials and coatings that resist fouling and scaling are of particular interest.

Advanced sensor technology enables real-time monitoring of salinity gradient systems [50], [51]. This data can be used for precise control, optimizing energy extraction, and ensuring the longevity of equipment. Incorporating automation and artificial intelligence (AI) can enhance the efficiency of energy extraction. AI algorithms can optimize system parameters, predict maintenance needs, and reduce energy wastage [52], [53]. Additive manufacturing, or 3D printing, allows for the creation of intricate components with precision. It has the potential to revolutionize the manufacturing of custom-designed parts for salinity gradient systems, improving their performance and efficiency. Innovative energy recovery devices, such as pressure exchangers, can capture and reuse energy that would otherwise be lost. These devices contribute significantly to overall system efficiency. The most significant advancements often occur when novel materials and technologies are integrated into a holistic system. For instance, combining advanced membranes with energy recovery devices can maximize energy extraction efficiency. The development and adoption of these new materials and technologies require extensive research and development efforts [54]. Collaboration between academia, industry, and government entities is vital to drive innovation forward and ensure its practical implementation. Material and technology innovation are pivotal in unlocking the full potential of energy extraction from salinity gradients. As Indonesia seeks to harness its coastal resources for sustainable energy, these advancements will play a central role. By continuously exploring and applying cutting-edge materials and technologies, Indonesia can significantly increase energy conversion efficiency, reduce environmental impacts, and pave the way for a cleaner, more sustainable energy future.

4. Conclusion

The paper aimed to comprehensively review energy extraction technologies in Indonesia. It began by highlighting the country's increasing energy demand, projected to rise by 10% by 2030. The paper emphasized the vast potential of extracting energy from sea and saline brines, supported by data on Indonesia's abundant coastline and seawater resources. The research methodology quantitatively evaluated various extraction technologies, including PRO, RO, and electrodialysis, to provide a clear overview of their efficiency. Challenges identified included environmental concerns and economic feasibility, quantitatively illustrating the barriers to implementing salinity gradient energy solutions. Collaboration among academia, industry, and government entities emerged as a quantitative cornerstone to optimize technology development and mitigate environmental impacts. The paper also quantitatively outlined future directions, including exploring hybrid systems, enhancing efficiency by up to 30%, improving energy conversion efficiency by up to 15%, and investigating novel materials and technologies. It quantitatively affirmed that successful energy extraction can align with Indonesia's commitments under the Paris Agreement, positioning the country for a sustainable energy future.

Indonesia's sustainable energy development stands at a pivotal juncture due to rising energy demands driven by population growth and economic expansion. The path forward requires a multifaceted approach, emphasizing the importance of strong policies and cross-sector collaboration. These policies, which may include incentives for renewable energy and emissions standards, could potentially reduce carbon emissions by 2030. To accelerate progress, collaboration among government, industry, and academia is indispensable, as it significantly enhances project efficiency. Quantitative analysis provides valuable insights, underlining that strategic investments in renewable energy infrastructure can create jobs and spur economic growth. emphasizing the interconnectedness of sustainability and economic prosperity. In summary, Indonesia's path to sustainable energy hinges on effective policy development and cross-sector collaboration, supported by quantitative data and analysis. This approach positions Indonesia to achieve its sustainable energy goals, contributing to global climate change mitigation and the promotion of a sustainable future.

References

[1] S. Indonesia, "Badan pusat statistik," *BPS-Statistics Indones.*, 2018.
[2] P. Agreement, "Paris agreement," in *report of the conference of the parties to the United Nations framework convention on climate change (21st session, 2015: Paris). Retrived December*, HeinOnline, 2015, p. 2017.
[3] M. Tawalbeh, A. Al-Othman, N. Abdelwahab, A. H. Alami, and A. G. Olabi, "Recent developments in pressure retarded osmosis for desalination and power generation," *Renew. Sustain. Energy Rev.*, vol. 138, p. 110492, 2021.
[4] M. Sharma, P. P. Das, A. Chakraborty, and M. K. Purkait, "Clean energy from salinity gradients using pressure retarded osmosis and reverse electrodialysis: A review," *Sustain. Energy Technol. Assessments*, vol. 49, p. 101687, 2022.
[5] Y. Shi, M. Zhang, H. Zhang, F. Yang, C. Y. Tang, and Y. Dong, "Recent development of pressure retarded osmosis membranes for water and energy sustainability: A critical review," *Water Res.*, vol. 189, p. 116666, 2021.
[6] N. AlZainati *et al.*, "Pressure retarded osmosis: Advancement, challenges and potential," *J. Water Process Eng.*, vol. 40, p. 101950, 2021.
[7] F. E. Ahmed, R. Hashaikeh, and N. Hilal, "Hybrid technologies: The future of energy efficient desalination–A review," *Desalination*, vol. 495, p. 114659, 2020.
[8] A. Panagopoulos and K.-J. Haralambous, "Environmental impacts of desalination and brine treatment-Challenges and mitigation measures," *Mar. Pollut. Bull.*, vol. 161, p. 111773, 2020.
[9] Z. M. Ghazi, S. W. F. Rizvi, W. M. Shahid, A. M. Abdulhameed, H. Saleem, and S. J. Zaidi, "An overview of water desalination systems integrated with renewable energy sources," *Desalination*, vol. 542, p. 116063, 2022.
[10] A. Panagopoulos, "A comparative study on minimum and actual energy consumption for the treatment of desalination brine," *Energy*, vol. 212, p. 118733, 2020.
[11] A. Panagopoulos, "Brine management (saline water & wastewater effluents): Sustainable utilization and resource recovery strategy through Minimal and Zero Liquid Discharge (MLD & ZLD) desalination systems," *Chem. Eng. Process. Intensif.*, vol. 176, p. 108944, 2022.
[12] A. N. Shocron, R. S. Roth, E. N. Guyes, R. Epsztein, and M. E. Suss, "Comparison of ion selectivity in electrodialysis and capacitive deionization," *Environ. Sci. Technol. Lett.*, vol. 9, no. 11, pp. 889–899, 2022.
[13] G. Doornbusch, H. Swart, M. Tedesco, J. Post, Z. Borneman, and K. Nijmeijer, "Current utilization in electrodialysis: Electrode segmentation as alternative for multistaging," *Desalination*, vol. 480, p. 114243, 2020.
[14] A. Shadravan, M. Amani, and A. Jantrania, "Feasibility of thin film nanocomposite membranes for clean energy using pressure retarded osmosis and reverse electrodialysis," *Energy Nexus*, vol. 7, p. 100141, 2022.
[15] P. Sahu, "A comprehensive review of saline effluent disposal and treatment: conventional practices, emerging technologies, and future potential," *Water Reuse*, vol. 11, no. 1, pp. 33–65, 2021.
[16] A. Suresh, G. T. Hill, E. Hoenig, and C. Liu, "Electrochemically mediated deionization: a review," *Mol. Syst. Des. Eng.*, vol. 6, no. 1, pp. 25–51, 2021.
[17] A. A. Hassan and M. M. Awad, "Bibliometric Analysis on Hybrid Renewable Energy-Driven Desalination Technologies," *Energy Nexus*, p. 100215, 2023.
[18] A. Mahmoudi, M. Bostani, S. Rashidi, and M. S. Valipour, "Challenges and opportunities of desalination with renewable energy resources in Middle East countries," *Renew. Sustain. Energy Rev.*, vol. 184, p. 113543, 2023.
[19] G. A. Tiruye, A. T. Besha, Y. S. Mekonnen, N. E. Benti, G. A. Gebreslase, and R. A. Tufa, "Opportunities and challenges of renewable energy production in Ethiopia," *Sustainability*, vol. 13, no. 18, p. 10381, 2021.
[20] L. Cremonese, G. K. Mbungu, and R. Quitzow, "The sustainability of green hydrogen: An uncertain proposition," *Int. J. Hydrogen Energy*, vol. 48, no. 51, pp. 19422–19436, 2023.
[21] M. D. Leonard, E. E. Michaelides, and D. N. Michaelides, "Energy storage needs for the substitution of fossil fuel power plants with renewables," *Renew. Energy*, vol. 145, pp. 951–962, 2020.
[22] K. Kumar and B. Jaipal, "The role of energy storage with renewable electricity generation," *Electr. Grid Mod.*, 2022.
[23] B. P. Statistik, "Statistik Sumberdaya Laut dan Pesisir Perikanan Berkelanjutan," *Badan Pus. Stat. Jakarta 256hal*, 2021.
[24] R. Csalódi, T. Czvetkó, V. Sebestyén, and J. Abonyi, "Sectoral analysis of energy transition paths and greenhouse gas emissions," *Energies*, vol. 15, no. 21, p. 7920, 2022.
[25] B. K. Sovacool, S. Griffiths, J. Kim, and M. Bazilian, "Climate change and industrial F-gases: A critical and systematic review of developments, sociotechnical systems and policy options for reducing synthetic greenhouse gas emissions," *Renew. Sustain. Energy Rev.*, vol. 141, p. 110759, 2021.
[26] J. C. Kelly, M. Wang, Q. Dai, and O. Winjobi, "Energy, greenhouse gas, and water life cycle analysis of lithium carbonate and lithium hydroxide monohydrate from brine and ore resources and their use in lithium ion battery

cathodes and lithium ion batteries," *Resour. Conserv. Recycl.*, vol. 174, p. 105762, 2021.
[27] A. Zoungrana and M. Çakmakci, "From non-renewable energy to renewable by harvesting salinity gradient power by reverse electrodialysis: A review," *Int. J. Energy Res.*, vol. 45, no. 3, pp. 3495–3522, 2021.
[28] K. E. Mueller, J. T. Thomas, J. X. Johnson, J. F. DeCarolis, and D. F. Call, "Life cycle assessment of salinity gradient energy recovery using reverse electrodialysis," *J. Ind. Ecol.*, vol. 25, no. 5, pp. 1194–1206, 2021.
[29] E. J. Okampo and N. Nwulu, "Optimisation of renewable energy powered reverse osmosis desalination systems: A state-of-the-art review," *Renew. Sustain. Energy Rev.*, vol. 140, p. 110712, 2021.
[30] W. Leal Filho *et al.*, "The unsustainable use of sand: Reporting on a global problem," *Sustainability*, vol. 13, no. 6, p. 3356, 2021.
[31] I. Douglas, "Urban geomorphology," in *The Routledge handbook of urban ecology*, Routledge, 2020, pp. 186–209.
[32] K. G. Nayar, J. Fernandes, R. K. McGovern, K. P. Dominguez, A. McCance, and B. S. Al-Anzi, "Cost and energy requirements of hybrid RO and ED brine concentration systems for salt production," *Desalination*, vol. 456, pp. 97–120, 2019.
[33] V. Lundaev, A. A. Solomon, U. Caldera, and C. Breyer, "Material extraction potential of desalination brines: A technical and economic evaluation of brines as a possible new material source," *Miner. Eng.*, vol. 185, p. 107652, 2022.
[34] I. Ihsanullah, J. Mustafa, A. M. Zafar, M. Obaid, M. A. Atieh, and N. Ghaffour, "Waste to wealth: A critical analysis of resource recovery from desalination brine," *Desalination*, vol. 543, p. 116093, 2022.
[35] M. Khan, R. S. Al-Absi, M. Khraisheh, and M. A. Al-Ghouti, "A better understanding of seawater reverse osmosis brine: Characterizations, uses, and energy requirements," *Case Stud. Chem. Environ. Eng.*, vol. 4, p. 100165, 2021.
[36] A. J. Mahardhani, "The Role of Public Policy in Fostering Technological Innovation and Sustainability," *J. Contemp. Adm. Manag.*, vol. 1, no. 2, pp. 47–53, 2023.
[37] S. Danladi, M. S. V Prasad, U. M. Modibbo, S. A. Ahmadi, and P. Ghasemi, "Attaining Sustainable Development Goals through Financial Inclusion: Exploring Collaborative Approaches to Fintech Adoption in Developing Economies," *Sustainability*, vol. 15, no. 17, p. 13039, 2023.
[38] S. Yu, M. Ally, and A. Tsinakos, *Emerging technologies and pedagogies in the curriculum*. Springer, 2020.
[39] H. Liu, H. Fu, L. Sun, C. Lee, and E. M. Yeatman, "Hybrid energy harvesting technology: From materials, structural design, system integration to applications," *Renew. Sustain. energy Rev.*, vol. 137, p. 110473, 2021.
[40] J. Zhang, Z. Cheng, X. Qin, X. Gao, M. Wang, and X. Xiang, "Recent advances in lithium extraction from salt lake brine using coupled and tandem technologies," *Desalination*, vol. 547, p. 116225, 2023.
[41] Y. Noorollahi, A. Golshanfard, A. Aligholian, B. Mohammadi-ivatloo, S. Nielsen, and A. Hajinezhad, "Sustainable energy system planning for an industrial zone by integrating electric vehicles as energy storage," *J. Energy Storage*, vol. 30, p. 101553, 2020.
[42] K. Elsaid, M. Kamil, E. T. Sayed, M. A. Abdelkareem, T. Wilberforce, and A. Olabi, "Environmental impact of desalination technologies: A review," *Sci. Total Environ.*, vol. 748, p. 141528, 2020.
[43] K. Elsaid, E. T. Sayed, M. A. Abdelkareem, A. Baroutaji, and y A. G. Olabi, "Environmental impact of desalination processes: Mitigation and control strategies," *Sci. Total Environ.*, vol. 740, p. 140125, 2020.
[44] A. Ghaffari and A. Askarzadeh, "Design optimization of a hybrid system subject to reliability level and renewable energy penetration," *Energy*, vol. 193, p. 116754, 2020.
[45] K. Jiao *et al.*, "Designing the next generation of proton-exchange membrane fuel cells," *Nature*, vol. 595, no. 7867, pp. 361–369, 2021.
[46] R. M. DuChanois, C. J. Porter, C. Violet, R. Verduzco, and M. Elimelech, "Membrane materials for selective ion separations at the water–energy nexus," *Adv. Mater.*, vol. 33, no. 38, p. 2101312, 2021.
[47] K. Zuo *et al.*, "Selective membranes in water and wastewater treatment: Role of advanced materials," *Mater. Today*, vol. 50, pp. 516–532, 2021.
[48] R. R. Gonzales *et al.*, "Salinity gradient energy generation by pressure retarded osmosis: A review," *Desalination*, vol. 500, p. 114841, 2021.
[49] R. A. Tufa *et al.*, "Salinity gradient power reverse electrodialysis: Cation exchange membrane design based on polypyrrole-chitosan composites for enhanced monovalent selectivity," *Chem. Eng. J.*, vol. 380, p. 122461, 2020.
[50] V. A. Memos and K. E. Psannis, "UAV-based smart surveillance system over a wireless sensor network," *IEEE Commun. Stand. Mag.*, vol. 5, no. 4, pp. 68–73, 2021.
[51] J. Park, K. T. Kim, and W. H. Lee, "Recent advances in information and communications technology (ICT) and sensor technology for monitoring water quality," *Water*, vol. 12, no. 2, p. 510, 2020.
[52] T. Ahmad *et al.*, "Artificial intelligence in sustainable energy industry: Status Quo, challenges and opportunities," *J. Clean. Prod.*, vol. 289, p. 125834, 2021.
[53] T. Ahmad, R. Madonski, D. Zhang, C. Huang, and A. Mujeeb, "Data-driven probabilistic machine learning in sustainable smart energy/smart energy systems: Key developments, challenges, and future research opportunities in the context of smart grid paradigm," *Renew. Sustain. Energy Rev.*, vol. 160, p. 112128, 2022.
[54] V. A. Safitri, L. Sari, and R. R. Gamayuni, "Research and Development (R&D), Environmental Investments, to Eco-Efficiency, and Firm Value," *Indones. J. Account. Res.*, vol. 22, no. 3, 2020.