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Unlocking renewable energy potential: Overcoming barriers and accelerating the transition

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ABSTRACT

Background: Indonesia's energy transition is driven by increasing energy demands, economic growth, as well as the pressing need to address climate change. Despite possessing vast renewable energy resources, the country faces significant challenges in shifting from a fossil-fuel-dominated energy mix to a more sustainable one. While Indonesia has vast potential in solar, wind, hydro, biomass, geothermal, and ocean energy, the adoption of renewable energy remains limited. This paper seeks to understand the barriers hindering renewable energy development in Indonesia and identify opportunities to accelerate the transition. **Methods:** This study uses Systematic Literature Review (SLR) with the PRISMA protocol to analyze renewable energy in Indonesia, using sources from Google Scholar and Science Direct. Literature selection based on relevance, quality, and recency, resulted in 37 publications that were analyzed narratively to identify challenges, developments, and potential of renewable energy in Indonesia. **Findings:** The results reveal that Indonesia's renewable energy utilization is significantly below its potential, contributing less than 10% to the energy mix. Major barriers include economic feasibility concerns, regulatory and policy inconsistencies, insufficient financial and technical support, and a heavy reliance on coal. Additionally, the study highlights substantial renewable energy resources available, such as the 443 GW potential from various sources, which remain largely untapped. **Conclusion:** Achieving Indonesia's renewable energy targets requires addressing these barriers through clear and consistent policies, improved regulatory frameworks, and enhanced financial and technical support. The study suggests leveraging the country's geographical advantages and diverse renewable resources to significantly contribute to a sustainable energy future. **Novelty/Originality of this article:** This article provides a comprehensive analysis of Indonesia's renewable energy challenges and opportunities using a systematic approach. By quantifying the untapped 443 GW potential and identifying specific barriers, it offers insights into strategic policy measures and investment directions to accelerate the country's transition to sustainable energy.

KEYWORDS: energy consumption; renewable energy; renewable energy potential.

1. Introduction

In recent years, we have witnessed increasingly unpredictable and extreme weather phenomena from an abrupt change of climate caused by human activities. Weather anomalies such as prolonged heat waves, flash floods, and forest fires have become a major concern for the scientific community, governments, and society. This phenomenon raises concerns about its impact on the environment, human life, and the sustainability of the global ecosystem.

Human activities, particularly urbanization, industrial processes, and transportation, are the primary drivers of climate change through the emission of greenhouse gases (GHGs).

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These gases accumulate in the atmosphere, retaining heat and causing a steady rise in the Earth's overall temperature, a process referred to as global warming. (Kabir et al., 2023). This warming trend is evident in the 2022 average global temperature, which exceeded the 20th-century mean of 13.9°C by about 0.86°C (Wang et al., 2023). Unusual weather patterns such as rising sea levels, more powerful tropical cyclones, flooding, severe heatwaves, wildfires, and unusually cold winter storms are strongly linked to the primary consequences of climate change. Sea levels will rise, more glacier ice will melt, and ocean surface temperatures will rise as a result of continued global warming (Chen et al., 2023).

Before the industrial revolution, natural phenomena such as forest fires, volcanic eruptions, and earthquakes were the primary sources of greenhouse gas (GHG) emissions, releasing carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) into the atmosphere (Yue & Gao, 2018). However, the advent of industrialization marked a significant shift, with human activities now identified as the dominant contributor to GHG emissions (Moiceanu & Dinca, 2021). This is particularly evident in urban areas, which, despite occupying less than 3% of the Earth's surface, account for a staggering 75% of GHG emissions (Omranian et al., 2023). The industrial revolution, while a catalyst for progress, ushered in an era of intensified human activities that have profoundly impacted the climate. These activities encompass a wide range of practices, including intensive agriculture reliant on fuel-powered machinery, the burning of agricultural waste, the combustion of fossil fuels for energy, extensive deforestation, and the rapid expansion of transportation systems at both national and domestic levels. The cumulative effect of these anthropogenic activities has been a surge in GHG emissions, triggering a cascade of climatic catastrophes with devastating consequences for local and global infrastructure, human health, and overall productivity (Abbass et al., 2022).

The escalating global energy consumption, particularly in developing nations where fossil fuels dominate energy production, has significantly contributed to the alarming rise in greenhouse gas (GHG) emissions, fuelling the concerning trend of global warming (Carvalheira et al., 2023). Over the past seven decades, carbon dioxide emissions from fossil fuel use have surged significantly, increasing from approximately 5 billion metric tons in 1950 to around 35 billion metric tons by 2020 (Perera & Nadeau, 2022). For decades, people have depended on fossil fuels for energy production. Fossil fuels are considered non-renewable resources due to the fact that their formation requires millions of years, and their extraction rates far exceed their replenishment rates. As fossil fuels are depleted, there is a risk of resource shortages and increased costs for energy production. This depletion could have significant implications for global economies, leading to the need for a rapid transition to alternative energy sources (Holechek et al., 2022).

The increasing concern regarding GHG and the escalating threat of climate change have brought about a heightened global awareness about the critical importance of conserving energy and transitioning to alternative energy sources. This growing consciousness has prompted nations and cultures worldwide to actively seek viable alternatives to conventional energy sources. A key strategy in this endeavor is the substitution of conventional energy with renewable energy, thus highlighting renewable energy as a crucial and substantial alternative energy source (Rehman et al., 2022). Renewable energy, derived from sources that naturally replenish, has emerged as a central focus in this transformative shift. Notably, the utilization of renewable energy sources such as solar, biomass, wind, hydroelectricity, and various others has garnered significant attention (Voumik et al., 2023). These renewable technologies, often referred to as alternative energies, encompass resources that can be harnessed repeatedly to generate energy, including the sun, wind, bioenergy, groundwater, and other such sustainable sources (Algarni et al., 2023).

Indonesia, along with other countries that heavily rely on fossil fuels and other non-renewable resources, needs the adoption of renewable energy sources. Indonesia's energy consumption rates are among the fastest growing in the world, primarily due to continued economic growth, urbanization, and increasing population (Adrian et al., 2023). Indonesia's energy consumption increased by about 231% between 2000 and 2021. Coal was the

dominant energy source in 2021, contributing to around 61% of total energy generation (IEA, 2021). Indonesia has set a target of achieving a 23% share of renewable energy in its overall energy mix by 2025, representing an approximate 7% increase from 2016 levels. According to data from the Ministry of Energy and Mineral Resources, the share of renewables in Indonesia's total energy consumption grew from 9.15% in 2019 to 11.51% in 2020. However, this growth is still below 2025 target (Sumarno et al., 2022). Renewable energy constitutes merely around 6% of Indonesia's total energy consumption (Pambudi et al., 2023), highlighting a clear disparity between established targets and actual implementation. Despite possessing substantial renewable energy potential, Indonesia's deployment of these resources remains limited.

Based on initial analysis above, the following research questions are formulated: (1) what is the current state of renewable energy in Indonesia (2) what are the challenges on the implementation of renewable energy in Indonesia and (3) what are the opportunities of renewable energy in Indonesia. To answer these questions, a Systematic Literature Review (SLR) is carried out. A Systematic Literature Review is a method to search, identify, abstract, evaluate and synthesize comprehensive and extensively existing literatures that are relevant to the research questions of the topic of interest (Janjua et al., 2021). The findings of this study are anticipated to contribute to future research and enhance the understanding of renewable energy potential. The study's novelty lies in its incorporation of the most recent data concerning the availability and development of renewable energy in Indonesia.

2. Methods

The method that employed in this study is Systematic Literature Review (SLR). The researchers explore scientific publications using online article databases such as Google Scholar and Science Direct. Science Direct, primarily provided internationally published research, while Google Scholar supplemented this study with publications found in Indonesian national journals or topic related to renewable energy implementation in the context of Indonesia. This dual approach aimed to ensure a more comprehensive understanding of the topic, particularly within the Indonesian context. The keywords explored in constructing this article are "Energy consumption", "Renewable energy", and "Renewable energy potential".

Literature selection for this study was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol (https://prisma-statement.org/). The literature selection for this study prioritized recent publications to ensure the inclusion of up-to-date data on the state, challenges, and potential of renewable energy in Indonesia. The initial screening involved reviewing titles and abstracts to identify studies that specifically addressed the current landscape of renewable energy in Indonesia, including its development, challenges, and prospects. Studies sourced from proceedings or studies focusing on specific technologies outside the scope of this study were excluded, for example the literature about "Technological Advancements in Specific Renewable Energy Technologies". Table 1 present the result of the criteria that applied when conducting this study by adapting PRISMA framework.

Table 1. Criteria used to conduct the study

	PRISMA Checklist
Eligibility criteria	Include the state-of-the-art literature with 30 or more citation from Journal article, textbook, and report written in English Language
Information sources	Science Direct Google Scholar
Search strategy	Keywords: Energy consumption Renewable energy Renewable energy potential
Selection process	After filtering using eligible criteria and filtering by relevant title, then the results from proceedings, blog, and Wikipedia is excluded,

	sources written in *Bahasa Indonesia* is reduced unless there are no comparable and relevant literatures written in English.
Data collection process	After selection process is carried out, the collected data is then reviewed first by both researchers to check whether the data is relevant to be included as a source of reference
Data items	All selected literatures were downloaded in full text PDF format for further review and added into Mendeley Reference Manager.
Synthesis	This step involves the synthesis of evidence or information included in each literature that is relevant to answer the research questions, the result of the synthesis will be presented in narrative format.

Following the initial screening, a full-text review of the selected articles was conducted to assess their relevance and quality. Studies that provided comprehensive and insightful analyses of the current state of renewable energy in Indonesia, along with a discussion of the challenges and opportunities facing the sector, were prioritized for inclusion. This rigorous selection process resulted in the identification of 37 relevant publications that form the basis of this study (Figure 1).

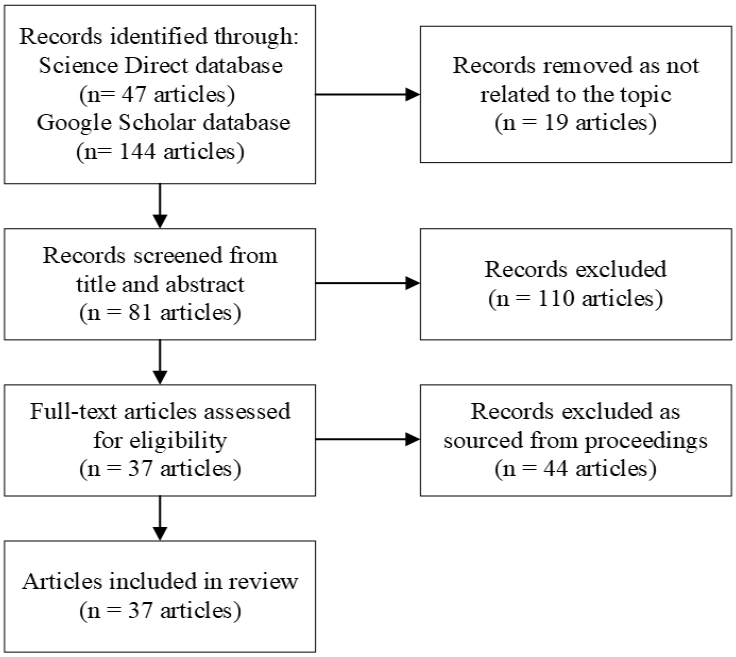

Fig. 1. Flow chart of the review process

3. Results and Discussions

3.1 Current state of renewable energy in Indonesia

Energy consumption in Indonesia is shaped by several critical factors. The nation is experiencing a significant increase in energy demand driven by its growing population and economic development. The growth of Indonesia's population, particularly within the middle-income demographic, significantly influences energy demand. Higher population density correlates with increased electricity and fuel consumption. However, the rise in electricity demand surpasses that of fuel, potentially attributed to the middle class's greater utilization of electricity for household appliances and daily activities compared to lower-income groups (Muzayanah et al., 2022). Table 2 illustrates the distribution of energy consumption across sectors in Indonesia, reflecting how energy is utilized in various economic and social activities within Indonesian society.

Table 2. Energy consumption by sector in Indonesia

Sector	Energy consumption (%)
Industrial	43.21
Households	12.97
Commercial	4.34
Transportation	38.49
Other	0.99

(Ministry of Energy and Mineral Resources Republic of Indonesia, 2022)

Based on Table 2, in 2022, Indonesia's energy consumption was dominated by the industrial sector, accounting for 43.21%, followed closely by transportation at 38.49%. Household and commercial sectors consumed 12.97% and 4.34% respectively, with a minor "other" category making up the remaining 0.99%. This breakdown highlights the significant energy demands of industrial activities and transportation in the country's energy landscape. Indonesia's energy consumption is predominantly reliant on non-renewable fuels including coal, crude oil, and natural gas, which form the backbone of its energy supply and dominate the energy mix despite the country's substantial potential for renewable energy sources (Agustinus et al., 2023). Between 2000 and 2014, Indonesia's energy consumption surged by about 65%, and this trend has continued, driven by factors such as economic growth, urbanization, and population increases. By 2022, the final energy consumption reached 1.114 million Barrels of Oil Equivalent (BOE), with industrial alone accounting for 43.21% of this total (Ministry of Energy and Mineral Resources Republic of Indonesia, 2022). The primary energy sources still fossil fuels pose significant threats, including the depletion of petroleum reserves, price volatility, and environmental pollution due to greenhouse gas emissions. The Indonesian government has acknowledged these issues and the need for a transition to renewable energy for both environmental sustainability and energy security. However, the progress toward renewable energy adoption has been slow, only about 12.30% of Indonesia's energy came from renewable sources (BPS-Statistics Indonesia, 2022), far from the targets of 23% by 2025 and 31% by 2050. Despite the vast potential of renewable energy in Indonesia, including solar, water, wind, bioenergy, geothermal, and mini hydro, the utilization rate is low. As of the latest data, only 7 GW of the potential 443 GW of renewable energy resources have been commercialized (Adrian et al., 2023). Indonesia's renewable energy potential is substantial, with estimates indicating 419 GW available from various sources. This includes 75 GW from hydropower, 23.7 GW from geothermal energy, 32.6 GW from bioenergy, 207.8 GW from solar power, 60.6 GW from wind energy, and 19.3 GW from micro-hydropower resources. Indonesia has set a goal to substantially raise the proportion of renewable energy in its overall energy mix to 31% by 2050, marking a notable increase from its current relatively low level (Pambudi et al., 2023).

According to 2022 data from Indonesia’s Ministry of Energy and Mineral Resources, Indonesia's power generation profile featured a varied array of energy sources, contributing to a total installed capacity of 83,813.09 megawatts (MW). While coal-fired power plants remained the predominant source, accounting for a substantial 42.38% of the overall capacity, the nation also harnessed the potential of other conventional and renewable resources. Natural gas constituted 13.92% of the total capacity, while oil-fired power plants contributed 31.40%. Additionally, hydropower and geothermal energy, representing 2.89% and 1.76% respectively, played a crucial role in diversifying the energy mix. Furthermore, Indonesia's commitment to embracing renewable energy was evident in the presence of solar photovoltaic (PV), wind, and biomass power plants, albeit with smaller contributions to the overall capacity. This multifaceted approach to power generation enabled Indonesia to achieve a total power production output of 333,537 gigawatt-hours (GWh) in 2022.

In 2022, renewable energy sources contributed less than 10% to Indonesia's primary energy mix, falling significantly short of the government's target of 23% by 2025. This contribution primarily comes from biodiesel, which is blended into transportation fuels.

Renewable electricity generation, mainly from hydropower and geothermal plants, constitutes only a small fraction of the total renewable energy supply. The growth of renewable energy within the power sector has been particularly slow, with only a 1 GW increase in installed capacity in 2023, missing the initial target of 3.4 GW. This slow growth is attributed to several factors, including delays in the implementation of hydro and geothermal projects. These delays are caused by various challenges, such as oversupply concerns, socio-environmental issues, and financial constraints. The slow growth of renewable electricity generation highlights the significant gap between the government's ambitious targets and the actual implementation on the ground (Yafi et al., 2023).

Despite having a strong legal basis, Indonesia's target of achieving a 23% renewable energy share by 2025 remains unfulfilled due to the reasons include economic feasibility concerns, varying RE targets across key documents, and the absence of a cohesive and coordinated regulatory framework. PT PLN and other utility business areas are mandated to incorporate renewable energy targets into their business plans, but only PLN's plans are publicly available, complicating the monitoring and synchronization of national targets. Additionally, the pricing regulations, which tie renewable energy purchases to PLN's base production cost, further hinder the attractiveness of renewable investments. These challenges, combined with internal budget limitations and delays in project feasibility preparations, have significantly slowed the progress toward the renewable energy target. The need for clear and consistent policies, improved monitoring, and better financial and technical support is critical for achieving the set goals (Swadana et al., 2024).

In the Indonesian power system, coal-fired power plants play a crucial role as base-load generators due to their abundance, affordability, and ease of transportation. Gas and diesel power plants, occupying the second and third largest shares in the energy mix, function as intermediate-load generators, leveraging their rapid ramping capabilities to adapt to fluctuations in electricity demand more effectively than coal. Meanwhile, renewable sources like hydro, wind, and geothermal primarily serve as peak-load generators due to their limited availability and intermittent nature. The intermittent nature of renewable energy, stemming from seasonal or weather-related variations, poses challenges to the reliability of the power system due to the strain caused by imbalances between electricity supply and demand (Kanugrahan et al., 2022).

Despite its immense renewable energy potential, Indonesia's renewable sector continues to encounter considerable challenges. Although the country is well-endowed with resources such as solar, wind, bioenergy, geothermal, and hydropower, the shift away from fossil fuels toward renewable alternatives has been notably slow. As of 2022, less than 10% of Indonesia's energy mix comes from renewable sources, falling short of the government's target of 23% by 2025. Key obstacles include economic feasibility concerns, regulatory inconsistencies, and insufficient financial and technical support. The reliance on coal-fired power plants due to their cost-effectiveness and ease of transportation also hampers the adoption of renewable energy. To fulfill its commitments to renewable energy development, Indonesia needs clearer policies, better monitoring, and enhanced financial and technical resources.

Table 3. Current State of Renewable Energy Utilization in Indonesia

No.	State	References
1	There is an increasing consumption of energy that resulted in higher demand of energy	Adrian et al. (2023), Agustinus et al. (2023), BPS (2022) Muzayanah et al. (2022), Kurniawan et al. (2022), Yafi et al. (2023), Kanugrahan et al. (2022), MEMRRI (2022), Pambudi et al. (2023), Sumarno et al. (2022)
2	Indonesia energy utilization is still predominated by the use of fossil fuel	Adrian et al. (2023), Agustinus et al. (2023), Muzayanah et al. (2022), Kurniawan et al. (2022), Yafi et al. (2023), Kanugrahan et al. (2022), MEMRRI (2022), Pambudi et al. (2023), Sumarno et al. (2022), Udemba & Phillip (2022)
3	The utilization of renewable energy in Indonesia still	Adrian et al. (2023), Agustinus et al. (2023), Kurniawan et al. (2022), Yafi et al. (2023), Kanugrahan et al. (2022),

	faces some challenges and barriers	Pambudi et al. (2023), Sumarno et al. (2022), Udemba & Phillip (2022), Umam et al. (2022), Voumik et al. (2023)
4	Renewable energy potential in Indonesia is still under-utilized	Adrian et al. (2023), Agustinus et al. (2023), BPS (2022), Hasanah et al. (2023), Kurniawan et al. (2022), Yafi et al. (2023), MEMRRI (2022), Pambudi et al. (2023), Resosudarmo et al. (2023), Sumarno et al. (2022), Umam et al. (2022)

As illustrated in Table 3, Indonesia's current energy landscape remains heavily dependent on fossil fuels, even as energy demand continues to rise and substantial renewable energy resources remain largely underutilized. While there is growing awareness and efforts to incorporate renewable energy sources, the utilization of these resources remains hindered by various challenges and barriers.

3.2 Challenges on the implementation of renewable energy in Indonesia

Renewable energy implementation in Indonesia faces several challenges hindering its progress towards a more sustainable energy landscape. One primary obstacle is policy uncertainty, creating an unstable environment for renewable energy development (Adrian et al., 2023). The regulatory environment for renewable energy in Indonesia is characterized by frequent changes and inconsistencies. This can involve abrupt shifts in policies, amendments to existing regulations, and the introduction of new rules that can alter the operating landscape for renewable energy projects. Such unpredictability makes it difficult for investors and developers to plan long-term projects, as they cannot rely on a stable policy framework (Udemba & Philip, 2022). Policy uncertainty can foster an unstable environment for renewable energy growth by adding ambiguity and unpredictability into the regulatory framework governing the sector. When policies related to renewable energy are unclear or subject to frequent changes, investors and developers may hesitate to commit resources to projects, leading to delays or cancellations in renewable energy initiatives. This uncertainty can deter strategic planning and investment in renewable energy infrastructure for the long term, as stakeholders may be unsure about the stability and longevity of supportive policies (Usman & Balsalobre-Lorente, 2022).

The challenges posed by policy uncertainty in renewable energy development are particularly evident in Indonesia, where issues such as financing barriers and market constraints are compounded by unclear and inconsistent policies. The lack of a clear and consistent policy direction in Indonesia hampers the growth of renewable energy projects, as investors may be reluctant to engage in ventures where the regulatory landscape is uncertain. Policy uncertainty can also lead to delays in project implementation and hinder the scaling up of renewable energy capacity in the country (Udemba & Philip, 2022). Similar to the challenges posed by policy uncertainty in renewable energy development in Indonesia, the power pricing regulations pose a significant barrier to renewable energy investments. These regulations often result in lower tariffs for electricity generated from renewable sources compared to conventional energy sources like coal. This pricing disparity discourages investment in renewable energy projects as investors find them less economically attractive. Moreover, the inflexible pricing structure fails to properly account for the actual costs and benefits of renewable energy, further limiting its appeal to potential investors. The lack of financial incentives and the unfavourable pricing framework pose significant challenges to the expansion of Indonesia's renewable energy (IEA, 2022).

The local manufacturing capacity for renewable energy technologies is low. Indonesia relies heavily on imported technologies, which can be expensive and subject to international market fluctuations. This dependency increases the overall cost of renewable energy projects and slows down their implementation (Udemba & Philip, 2022). The limited volume of renewables manufacturing in Indonesia is a significant barrier to the development of renewable energy in the country, hindering the growth and adoption of clean energy technologies. The environmental impact of renewable energy sources, such as

solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic energy, underscores the urgency of transitioning to cleaner energy alternatives. However, the insufficient volume of renewables manufacturing in Indonesia acts as a barrier to scaling up renewable energy infrastructure and minimizing the environmental impact of the energy sector. Without robust manufacturing capabilities for renewable energy technologies, Indonesia may struggle to achieve its environmental targets and mitigating the negative effects of conventional power generation on the environment (Rahman et al., 2022).

Indonesia's significant reliance on coal is deeply intertwined with its economy. In 2022, state revenue experienced a near doubling relative to the year before, primarily driven by the substantial tax revenue generated from coal commodities. This economic dependence on coal presents a significant hurdle to Indonesia's net-zero emission (NZE) goals. Coal power generation stands as the second-largest source of emissions in the country, following deforestation, and accounts for approximately 35% of Indonesia's total emissions, totalling 1,262 gigatonnes of carbon dioxide equivalent in 2020. In Indonesia, coal serves as both a cornerstone of the economy and a dominant energy source. The complex nature of an energy transition presents various challenges, including the financial resources required to invest in renewable energy infrastructure, as well as the economic impact of prematurely decommissioning coal power plants, the potential for job losses and income reduction, the costs associated with necessary institutional reforms, the possibility of increased electricity prices from renewable sources, the risk of stranded assets, and a decline in government revenue from coal-related taxes (Resosudarmo et al., 2023).

Economic barriers, such as competition with fossil fuels and reliance on government grants and subsidies, pose significant challenges to the deployment of renewable energy in Indonesia. The dominance of fossil fuels in the energy market, coupled with high initial capital costs and limited financial institution support, hinders the competitiveness of renewable energy technologies, and slows their adoption. The availability of financial resources and investment mechanisms is essential for scaling up renewable energy infrastructure and overcoming financial barriers that hinder project development (Sambodo et al., 2022). A major economic obstacle to renewable energy expansion in Indonesia is the high level of investment uncertainty. This uncertainty stems from the limited availability of data and information on renewable energy, coupled with a tightly regulated market environment. These factors create a hesitancy among investors to commit resources to renewable energy projects, leading to a decrease in investment and hindering the progress of clean energy initiatives (Umam et al., 2022).

The state-owned enterprise PLN's dominant position in the electricity sector and its historical focus on coal-based power generation have created significant barriers for private companies seeking to invest in renewable energy in Indonesia. Over the past decade, PLN has prioritized expanding the electricity supply based on optimistic economic growth projections, leading to the construction of coal-fired power plants (CFPPs) and agreements with private coal power plant operators. This emphasis on coal was further reinforced by a government program aiming to increase coal's share in the energy mix from 26% in 2008 to 33% by 2025. Consequently, coal-fired power plants have dominated energy development in recent years, making it challenging for renewable energy projects to gain traction (Resosudarmo et al., 2023).

Furthermore, PLN, which serves as the sole purchaser of electricity. Despite attempts to restructure and introduce competition, PLN retains control over generation, transmission, distribution, and retail of electricity across the country. Independent power producers (IPPs) are able to sell electricity to PLN through long-term power purchase agreements (PPAs), which provide financial stability but often include "take-or-pay" clauses. These clauses require PLN to purchase a minimum amount of power regardless of actual demand, limiting operational flexibility and the integration of renewable energy sources. PLN also controls the transmission and distribution infrastructure, although private operators can participate through build-operate-transfer (BOT) or build-lease-transfer (BLT) schemes to help alleviate PLN's investment burden while retaining overall control of the grid. This centralized structure, combined with regulatory and contractual

inflexibilities, poses challenges for the growth of renewable energy projects in Indonesia, despite the country's substantial renewable energy potential (IEA, 2022).

With a population of 270 million people spread across more than 17,000 islands, Indonesia is an archipelago characterized by uneven distribution across its various island groups. This uneven distribution results in disparities in resource availability and levels of economic development, leading to diverse energy system characteristics across the islands. As a rapidly growing economy, Indonesia has seen its GDP rise from USD 395 billion in 2000 to USD 1,049 billion in 2019 (measured at 2015 market exchange rates). Concurrently, the country's total primary energy supply has increased from 6.53 exajoules (EJ) to 10.09 EJ. The energy sector, which is predominantly dependent on fossil fuels, is the largest source of national CO_2 emissions. The power sector alone contributes 38% of emissions from fuel combustion, releasing 224 million tonnes of CO_2 in 2019. Over the past decades, the emissions intensity of the power sector has escalated, adding to the overall carbon footprint (IEA, 2022).

Table 4. Renewable energy implementation challenges in Indonesia

No.	Challenges	References
1	Policy uncertainty	Adrian et al. (2023), Udemba & Philip (2022), Usman & Balsalobre-Lorente (2022)
2	Power pricing regulations	IEA (2022)
3	Low local manufacturing capacity	Udemba & Philip (2022), Rahman et al. (2022)
4	Economic dependence on coal	Resosudarmo et al. (2023)
5	Economic barriers (competition, grants, etc.)	Sambodo et al. (2022), Umam et al. (2022)
6	PLN's dominance and focus on coal	Resosudarmo et al. (2023), IEA (2022)
7	Geographic and demographic challenges	IEA (2022)

Table 4 highlights the multifaceted challenges hindering the widespread adoption of renewable energy in Indonesia. These challenges range from policy inconsistencies and unfavorable pricing regulations to technological limitations, economic dependencies, and institutional barriers. Overcoming these obstacles necessitates a comprehensive approach that involves not only technological advancements but also policy reforms, economic incentives, and a shift in institutional focus. By addressing these challenges head-on, Indonesia can unlock its vast renewable energy potential and pave the way for a more sustainable and resilient energy future.

3.3 Opportunities for renewable energy utilization in Indonesia

Indonesia's energy consumption pattern indicates a critical need to accelerate the shift towards renewable energy. This transition is essential not only for meeting future energy demands sustainably but also for reducing the environmental impact of reliance on fossil fuels. Indonesia's substantial renewable energy resources offer a viable alternative to fossil fuels. By optimizing the use of existing renewable energy capacity, the country can greatly decrease its dependence on fossil fuels and support global initiatives to reduce GHG emissions. Recognizing this potential, the Indonesian government has made the sustainable development of renewable energy a priority as a key component of its national energy security and independence strategy. In line with Government Regulation No. 79 of 2014 on the National Energy Policy, the government has set ambitious targets for renewable energy to account for at least 23% of the energy mix by 2025 and 31% by 2050. Indonesia's vast renewable energy potential positions the country well to achieve these targets and transition towards a more sustainable energy future.

Indonesia is endowed with an impressive renewable energy potential, estimated to be around 443 gigawatts (GW). This abundant resource pool is primarily composed of solar power, which accounts for 49% (207 GW) of the total potential. Following solar, water

resources contribute 18%, wind accounts for 14%, bioenergy contributes 8%, geothermal contributes 6%, and mini-hydroelectric power contributes the remaining 5% (Adrian et al., 2023). This diverse range of renewable energy sources offers Indonesia a unique opportunity to transition towards a more sustainable energy system. Harnessing this potential could significantly reduce the country's dependence on fossil fuels, reduce GHG emissions, and support global efforts to address climate change. Furthermore, it could provide clean and reliable energy access to millions of Indonesians, particularly those in remote and underserved areas. However, despite this vast potential, the current utilization of renewable energy in Indonesia remains relatively low. Only 7 GW out of the total 443 GW of renewable resources are currently being harnessed and commercialized (Adrian et al., 2023). This indicates a significant untapped opportunity to harness the potential that could be leveraged to drive sustainable development and economic growth. The majority of the currently utilized renewable energy comes from hydro and geothermal power plants, which are primarily used for electricity generation. While these sources play a crucial role in the energy mix, there is a need to diversify the renewable energy portfolio by expanding the utilization of other sources such as solar, wind, and bioenergy.

Table 5 shows that Indonesia possesses a vast array of renewable energy resources, with an estimated total potential of approximately 3,692 GW. Indonesia's significant solar energy potential is primarily due to its strategic location along the equator, which ensures abundant sunlight throughout the year. This extensive solar irradiance makes solar photovoltaic (PV) systems highly effective and efficient. Recent studies highlight that Indonesia's vast maritime and land areas, including rooftops, reservoirs, and agricultural lands, are suitable for large-scale solar installations. These factors collectively position Indonesia as a promising leader in solar energy production, potentially transforming its energy landscape and contributing substantially to global renewable energy efforts (Silalahi et al., 2021), furthermore, electrification of end-uses, such as heating, transportation, and industrial processes, can significantly enhance the integration of solar PV into the energy system. By converting these end-uses from fossil fuels to electricity, the demand for electricity increases, creating a larger market for solar PV generation. This shift helps to balance the intermittent nature of solar energy by aligning electricity demand with peak solar generation periods. Additionally, electrification supports grid stability and efficiency, as it allows for better management of energy loads and reduces reliance on non-renewable energy sources. As a result, the broader adoption of solar PV becomes more feasible and economically attractive, promoting a more sustainable energy transition (IEA, 2022).

Table 5. Renewable energy opportunities in Indonesia

Type of energy	Potential (MW)
Solar	2,898,000
Offshore wind	589,000
Hydro	94,600
Biomass	43,300
Onshore wind	19,600
Ocean	17,900
Geothermal	29,500
Total	3,692,000

(Kurniawan et al., 2022)

Offshore wind energy also offers significant potential, with 589,000 MW, though it requires substantial investment and advanced technology to harness effectively. Onshore wind energy, while less extensive, still presents a notable potential of 19,600 MW. Hydropower resources add another 94,600 MW to Indonesia’s renewable energy portfolio, leveraging the nation’s numerous rivers and waterfalls. However, the variability in water availability can pose challenges. This variability is influenced by climatic oscillations and interannual changes in streamflow, which significantly impact the hydropower potential. Studies have shown that the effects of climate change, such as altered precipitation patterns and changing seasonal runoff, can lead to unpredictable water availability. This can result

in periods of water scarcity, which reduces hydropower generation capacity, and periods of excess, which may cause operational challenges (Borowski, 2022). Indonesia's hydro energy potential is immense, with a possible 94,627 MW spread across 52,566 sites using the run-of-river system. Despite this, development has been limited. State-owned PT PLN aims to develop 10.4 GW of hydropower by 2030, including 9.27 GW of large-scale hydro and 1.11 GW of micro-hydro plants, aligning with the 2021-2030 Electric Power Supply Business Plan. The country has also identified numerous sites for pumped storage hydropower (PSH), which is crucial for energy storage and grid stability. For instance, 657 potential PSH sites in Bali alone could provide a combined storage capacity of 2,300 GWh, more than enough to support a fully renewable grid. Additionally, Lake Toba in Sumatra has been highlighted for its PSH potential (Hasanah et al., 2023).

Biomass energy, with a potential of 43,300 MW, is another promising resource, especially given Indonesia's extensive agricultural sector and forestry resources. Biomass in Indonesia can be derived from a variety of sources, including agriculture, forestry, and organic waste. The country's large agricultural sector provides substantial amounts of residues that can be converted into bioenergy. Additionally, forestry resources and organic waste further bolster the potential for biomass energy production (Sertolli et al., 2022). The potential of renewable energy from oil palm biomass in Indonesia is significant, given the large quantities of oil palm biomass (OPB) produced as a byproduct of the palm oil industry. This biomass includes empty fruit bunches (EFB), palm kernel shells (PKS), mesocarp fiber (MF), oil palm fronds (OPF), and oil palm trunks (OPT). These byproducts, when not managed properly, contribute to environmental pollution. However, thermochemical upgrading processes such as torrefaction and pyrolysis offer promising methods for converting OPB into valuable products like solid fuel and biochar. Torrefied OPB can be used as a high-quality solid fuel, which is carbon-neutral and suitable for co-firing with coal to reduce greenhouse gas emissions. Pyrolyzed OPB produces biochar, which can be used for soil enhancement and carbon sequestration, further contributing to environmental sustainability. Additionally, the market for OPB-derived products is promising, particularly in renewable energy and agriculture sectors, supporting Indonesia's goals for net-zero emissions by 2060 (Nabila et al., 2023).

Indonesia has substantial potential for renewable energy derived from ocean sources, particularly wave and tidal energy. The country's extensive coastline and strategic geographic location between the Indian and Pacific Oceans result in significant and consistent ocean currents and waves. Areas like the Lombok Strait and Maluku Sea show high potential for ocean current energy, with estimated energy potentials of 1,035 Watts and 1,536 Watts, respectively. Similarly, the south coast of Java and Sumatra exhibits considerable wave energy potential, with Panaitan Island and Sangiang Island having potentials of 23,051 kW/m and 12,842 kW/m, respectively. Developing these resources can decrease dependence on fossil fuels, meet sustainable energy demands, and drive economic growth. However, the integration of ocean renewable energy must consider environmental impacts, particularly on marine habitats and biodiversity, to ensure sustainable development (Anggraini & Santoso, 2023).

Geothermal energy, with an estimated potential of 29,500 MW, is particularly noteworthy due to Indonesia's location on the Pacific Ring of Fire, which provides stable and reliable geothermal resources although it has comparably substantial risk and technology needed for further utilization. Despite this enormous potential, current utilization of these renewable resources remains limited (Pambudi & Ulfa, 2024). This highlights the need for strong policy frameworks, significant investments, and technological advancements to fully exploit these resources.

Table 6. Renewable Energy Opportunities in Indonesia

No.	Opportunities	References
1	There is a need to accelerate to transition to renewable energy	Adrian et al. (2023), Agustinus et al. (2023), Sambodo et al. (2022), Yafi et al. (2023)

2	Indonesia has abundant sources of renewable energy potential	Pambudi et al. (2023), Rahman et al. (2022), Nabila et al. (2023), Resosudarmo et al. (2023), Sambodo et al. (2022), Silalahi et al. (2021), Sertolli et al. (2022)
3	There is a room for optimization of renewable energy utilization	Sambodo et al. (2022), Pambudi & Ulfa (2024), Umam et al. (2022)
4	There is a need to diversify the renewable energy portfolio, therefore the use of renewable energy source such as solar, wind, bioenergy, or other sources is considered	Adrian et al. (2023), Silalahi et al. (2021), Hasanah et al. (2023), Pambudi et al. (2023), Resosudarmo et al. (2023), Sambodo et al. (2022)

Table 6 highlights the variety of opportunities for the utilization of Indonesia's renewable energy. Ranging from the growing need for transition to renewable energy, the abundance of sources of renewable energy potential in Indonesia that can be utilized, the opportunity to optimize further the current renewable energy utilization and lastly, there is a need for diversification of renewable energy utilization. It is evident that Indonesia possesses a significant potential for the utilization of renewable energy. The country's transition to renewable energy is not only a growing necessity but also a viable opportunity given the abundance of renewable energy sources available. Furthermore, there is potential for further optimization of current renewable energy utilization practices. However, to fully harness these opportunities, there is a need for diversification in the utilization of renewable energy sources. Therefore, Indonesia stands at a crucial juncture where strategic planning and policy implementation can result in a more sustainable and energy-efficient future.

4. Conclusion

In conclusion, Indonesia's journey towards a renewable energy-powered future is marked by both significant potential and substantial challenges. The nation's abundant renewable resources, spanning solar, hydro, wind, biomass, and geothermal energy, offer a promising pathway to reduce fossil fuel dependence, mitigate environmental impacts, and achieve energy security. However, realizing this potential requires overcoming hurdles such as policy inconsistencies, limited local manufacturing capacity, economic barriers, and the entrenched dominance of coal in the energy sector. A multifaceted approach is essential to navigate this complex landscape. Clear, consistent, and supportive policies are crucial to attract investment and foster a stable environment for renewable energy development. Enhancing local manufacturing capabilities can reduce reliance on imported technologies and create domestic economic opportunities. Addressing economic barriers, such as high upfront costs and competition with fossil fuels, necessitates innovative financing mechanisms and market incentives. Furthermore, diversifying the energy mix beyond coal and promoting public awareness about the benefits of renewable energy are vital steps towards a sustainable energy transition. Indonesia's goal of raising the share of renewable energy in its energy mix to 31% by 2050 is ambitious yet achievable. By leveraging its vast renewable resources, addressing existing challenges, and embracing technological advancements, Indonesia can pave the way for a cleaner, more resilient, and prosperous energy future for the nation. This paper's novelty lies in providing an updated and detailed understanding of the renewable energy landscape in Indonesia, identifying specific challenges and opportunities and offering practical recommendations for accelerating the transition to renewable energy. This comprehensive approach can serve as a source of reference for policymakers, researchers, and stakeholders involved in Indonesia's energy sector.

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Author Contribution
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