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Advancing Renewable Energy in Indonesia: A Comprehensive Analysis of Challenges, Opportunities, and Strategic Solutions

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Abstract: Indonesia's commitment to the early retirement of coal-fired power plants (CFPPs) underscores the urgent need to transition to renewable energy due to coal's significant contribution to environmental degradation and rising CO_2 emissions. Despite this urgency, several challenges impede the widespread adoption of renewable energy, including disparities in energy access, inadequate policy implementation, unreliable government financing mechanisms, and lack of education and awareness, especially due to the current incorporation of hydrogen and nuclear energy. To overcome these barriers, a robust policy framework is essential, complemented by progressive policy enactment. This study examines Indonesia's evolving energy landscape, highlighting key challenges and opportunities for the implementation of renewable energy. The findings emphasize that a comprehensive and integrated roadmap is critical to unlocking Indonesia's renewable energy potential. The roadmap includes strengthening governance, fostering public–private collaborations, and securing diverse financing channels, while offering targeted incentives, such as tax breaks and financial benefits. Furthermore, conducting pre-feasibility studies and regional assessments for emerging energy sources, like hydrogen and nuclear power, is crucial to accurately evaluate potential risks and opportunities. By addressing gaps in regulatory framework and enforcing effective policy measures, Indonesia can facilitate public–private partnerships, promote technology transfer, and develop skilled workforce as an effort to transition into a sustainable and diversified energy future.

Keywords: energy transition; government; policy framework; renewable energy; roadmap

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1. Introduction

Indonesia, as the Southeast Asia country with the largest economy value, is currently experiencing a vibrant domestic market that has powered annual Gross Domestic Product (GDP) growth, exceeding 5% since 2021, and is predicted to continually exceed this number. The high figure of Indonesia's annual GDP growth itself has surpassed the 4.2% cumulative growth of ASEAN-5 countries, indicating highly intense commodity manufacture and production processes in Indonesia's economic landscape [1,2].

The subsequent impact of GDP growth has led to an increase in electricity as energy demand, which is seen with a 5.36% increase in energy demand, resulting in an energy demand of 288.44 TWh in 2023 compared to 273.77 TWh in the previous year [3]. Furthermore, the actual energy demand has eclipsed the projected value of 4.9% annual increase, as mentioned in RUPTL (Electricity Supply Business Plan) 2021–2030 [4]. Currently, this annual demand is mostly fulfilled through coal-fired power plants (CFPPs), natural gas, and oil as conventional energy sources, contributing to around 85% share of Indonesia's power plant capacities, with 88.3% of total output [5].

The high number of conventional energy sources are directly and mainly attributed to the domineering figure of CFPPs, which shows that Indonesia has generated around 615 million tons in production, constructing around 49.93 GW of CFPPs in 2023 [5,6]. Furthermore, the Indonesian government has initiated a 35,000 MW coal power plant investment through a collaboration between *Perusahaan Listrik Negara* (PLN) and Independent Power Producer (IPPs), where PLN was planned to construct 10,681 MW, while private companies will account for 25,904 MW of coal power plant, indicating a consensus for the program [7,8].

However, there are ongoing concerns over the harmful environmental effects of conventional energies' utilization to Indonesia's landscape. In 2024, the energy sector is the second largest greenhouse gas (GHG) emitter, totaling 35% of Indonesia's total emissions, with annual CO_2 emissions having multiplied four times than what were in 2019 [9]. As a countermeasure, Indonesia has constructed a Nationally Determined Contribution (NDC) through the issuance of the Presidential Regulation No 112/2022 to diminish emissions by 314 million metric tons of CO_2 equivalent, achieving 31.89% reduction in GHG emissions by mandating the early retirement of CFPPs by 2030 and replacing the created gap with renewable energy [6,10].

Indonesia itself boasts a diverse array of available renewable energy resources to tackle the present gap created by the transition away from conventional energy, each with distinct characteristics and potential for development [11,12]. The energy sources themselves include hydropower, geothermal, biomass-based, solar panel, wind farm, or even ocean-based energy, as mentioned in RUPTL 2021–2030 [4,13]. Furthermore, there are also other areas with potential, for the Indonesian government has explored additional options to enforce Indonesia's energy security by developing hydrogen and nuclear-based energy as a type of renewable energy, which is waiting its realization.

Historically, the government has appointed targets for the country's energy transition under Government Regulation 79/2014 in the National Energy Policy. The aim is to decrease the coal contribution from 43% to 30% by 2025 and 25% by 2050, that of oil to less than 25% by 2025 and under 20% by 2050, and that of gas to 22% of the energy mix by 2025 and 24% by 2050 [14]. Furthermore, Indonesia also expects to utilize 23% of renewable electricity by 2025, 28% by 2038, and 31% by 2050 according to the Presidential Regulation No. 22/2017 in the National Energy Planning [13,15,16]. However, by 2024, Indonesia's renewable electricity only accounts for 11.5% from the total energy share, which is still a far cry from the intended projections [5].

The deviation from this policy might have been derived from several different factors, mainly from the limited investment made on Indonesia's renewable energy transition, which targeted that investment in renewable sources will reach around USD 4 billion in 2022, yet the actual investment only accounts for USD 1.6 billion. In addition, there are other obstacles to renewable energy investment, including complicated bureaucracies, limited technical capacities, lack of planning, and limited access to financing for IPPs [17].

To our knowledge, there is currently a lack of comprehensive research that systematically synthesizes Indonesia's renewable energy policy progression, particularly in the context of the emerging challenges and opportunities associated with the transition. This gap is even more pronounced in the planned incorporation of hydrogen and nuclear energy, which remain novel and largely unregulated within Indonesia's energy landscape. At present, there are no specific regulatory frameworks or enacted policies governing the integration of these energy sources.

To address this gap, this study aims to develop a comprehensive understanding of Indonesia's renewable energy transition, focusing on both challenges and opportunities. The existing literature often lacks a holistic assessment of policy implementation and its practical implications. Therefore, this research aims to fill the gap by providing a comprehensive analysis of the challenges, opportunities, and regulatory framework for sustainable renewable energy adoption in Indonesia. Subsequently, this research offers strategic insights for allocating investment decision and bypassing policy barriers, while exploring Indonesia's potential on leveraging renewable energy sources. Due to that, this research addresses two research questions, which are: (1) what are the key challenges and opportunities in Indonesia's current targeted renewable energy transition; and (2) what is the proposed regulatory and action framework necessary for the government to accelerate Indonesia's renewable energy transition.

This study employs a qualitative approach to analyze Indonesia's renewable energy transition through a quantitative data assessment to provide the comprehensive progression of Indonesia's renewable energy policy while also presenting an evaluation of the current renewable energy landscape in Indonesia, the actual challenges, and possible opportunities. After the current landscape, challenges, opportunities, and policy progression are analyzed, the suggested action and policy roadmap for the government are synthesized as a form of strategic insight.

A key novelty of this research lies in its integrated assessment of hydrogen and nuclear energy as emerging components of Indonesia's energy strategy. Unlike previous studies, which primarily focus on conventional renewable sources, this study incorporates hydrogen and nuclear energy into the policy roadmap, addressing the necessary actions and steps to incorporate both energies. The paper is structured as follows: Section 2 provides the renewable energy development in Indonesia and Section 3 presents an overview of Indonesia's energy market and regulations. Section 4 presents the challenges and opportunities to support renewable energy transition in Indonesia considering actual conditions. Section 5 summarizes key conclusions and recommendations.

2. Indonesia's Energy Mix and Potential

2.1. Solar Energy

In 2022, solar energy emerged as a critical component in Indonesia's pathway to net zero emissions, particularly through the deployment of solar photovoltaics (PVs). Analyses from multiple sources, including Ministry of Energy and Mineral Resources (MEMR), indicate solar energy's significant role in achieving deep decarbonization by the mid-century. In its 2060 net-zero power sector model, MEMR projects that solar PVs will account for at least one-third of the total electricity generation, with approximately 420 GW of installed capacity [6]. Supporting this projection, the International Energy Agency (IEA) forecasts a possible 340 GW of solar capacity by 2060 [6]. Given these favorable projections, Perusahaan Listrik Negara (PLN) aims to add 4.68 GW of solar energy capacity by 2030, as outlined in the RUPTL 2021 plan, with the phased installation by PLNs and IPPs shown in Table 1.

Recently, advancements in solar PV deployment in Indonesia have increasingly focused on rooftop solar PV systems. In 2022, initiatives were launched to install rooftop solar panels on 70 ministry and agency buildings, supporting Indonesia's commitment to expanding rooftop solar PV projects nationwide [18]. Further measures were introduced under MEMR Regulation No. 2/2024 to enhance the implementation of rooftop solar PVs through improvements in efficiency and transparency [19]. This regulation streamlines policies on rooftop solar power by updating provisions on capacity limits, electricity export–

import mechanisms, and the total capacity charges, thereby facilitating a broader adoption and optimizing the system's functionality across the country.

Table 1. Solar capacity construction plan [6].

Year	Planned Solar Capacity Construction	
	PLNs	IPPs
2021	59 MW	1 MW
2022	126 MW	162 MW
2023	237 MW	1070 MW
2024	266 MW	358 MW
2025	773 MW	858 MW
2026	17 MW	110 MW
2027	8 MW	140 MW
2028	25 MW	140 MW
2029	32 MW	140 MW
2030	157 MW	0

2.2. Hydropower Energy

Hydropower currently holds the largest share of renewable energy in Indonesia's electricity mix, having generated 19.97 TWh, or 6.19% of the country's total electrical output, in 2023 [5]. This share is expected to grow as hydropower development remains a priority for the government, given its capacity to provide consistent, long-term baseload power essential for reaching Indonesia's target of 23% renewable energy by 2025. However, while plans are in place to double the hydropower capacity by 2025, potential constraints, such as flooding risks, environmental degradation, and climate change impacts, may pose challenges to these goals [20].

Despite these risks, significant projects, including the Cirata Hydroelectric Power Plant with an installed capacity of 1008 MW and the Saguling Hydroelectric Power Plant with 700 MW, underscore Indonesia's commitment to hydropower development [21]. However, these projects have faced operational and environmental challenges that could affect their long-term viability, especially on the Saguling site. For instance, the Saguling site has experienced sedimentation accumulation, which has reduced its generation capacity annually [22]. On the contrary, the Cirata site has also suffered water pollution, largely driven by agricultural runoff and aquaculture waste, diminishing the effectivity of water quality and turbine performance [23]. These factors highlight that there are necessary steps that must be undertaken to sustain the hydropower contribution to Indonesia's landscape, considering its position as the highest source of renewable energy in Indonesia.

As of 2024, Indonesia's installed hydropower capacity stands at approximately 6780 MW, with an additional untapped potential of around 87,500 MW, underscoring hydropower's critical role in the country's energy portfolio [5]. This is particularly evident in West Sumatra, where mini- and micro-hydropower plants serve remote communities, capitalizing on the region's significant hydropower resources. These smaller-scale hydropower systems are highly valued due to the local expertise in their operation, ease of maintenance, and low operating costs, collectively representing an estimated 3.6 GW potential in West Sumatra [6]. Indonesia's hydropower potential is shown in Table 2.

Table 2. Indonesia's hydropower energy potential [17].

Island	Hydropower Energy Potential	
	Hydro (GW)	Micro-Hydro (GW)
Sumatera	15.6	5.73
Java	4.2	2.91
Kalimantan	21.6	8.10
Sulawesi	10.20	1.67
Bali and Nusa Tenggara	0.62	0.14
Maluku	0.43	0.21
Papua	22.35	0.62
Total	**75.00**	**19.37**

2.3. Wind Energy

Indonesia, with its extensive coastal and mountainous regions, holds substantial potential for wind energy production, with many areas identified as favorable for wind development. However, large-scale wind energy deployment remains limited, primarily due to technological constraints and variability in wind speeds, which lower capacity factors and hinder the optimal output [20]. As of 2023, Indonesia's wind energy capacity stands at 0.15 GW, generating 0.48 TWh—equating to just 0.16% of the total power plant capacity and 0.15% of the national electricity output, which is a very low number compared to other renewable energies [5].

In 2022, Indonesia was identified as having the third-highest wind energy potential in Southeast Asia, following Vietnam. Nevertheless, the average annual wind speeds in Indonesia are in the range of 3–6 m/s, about half of the speeds in northern and southern hemisphere countries, where wind speeds exceed 8 m/s. This difference is attributed to Indonesia's equatorial position, which results in warm air and low-pressure systems [24]. Despite these challenges, the Ministry of Energy and Mineral Resources (MEMR) has estimated Indonesia's technical wind power potential at approximately 60.6 GW, especially concentrated in areas like South Sulawesi, West Nusa Tenggara, and East Nusa Tenggara. Notable examples include the Sidrap Wind Farm in South Sulawesi, with an installed capacity of 75 MW [6]. Additionally, Indonesia's onshore wind potential is shown in Figure 1.

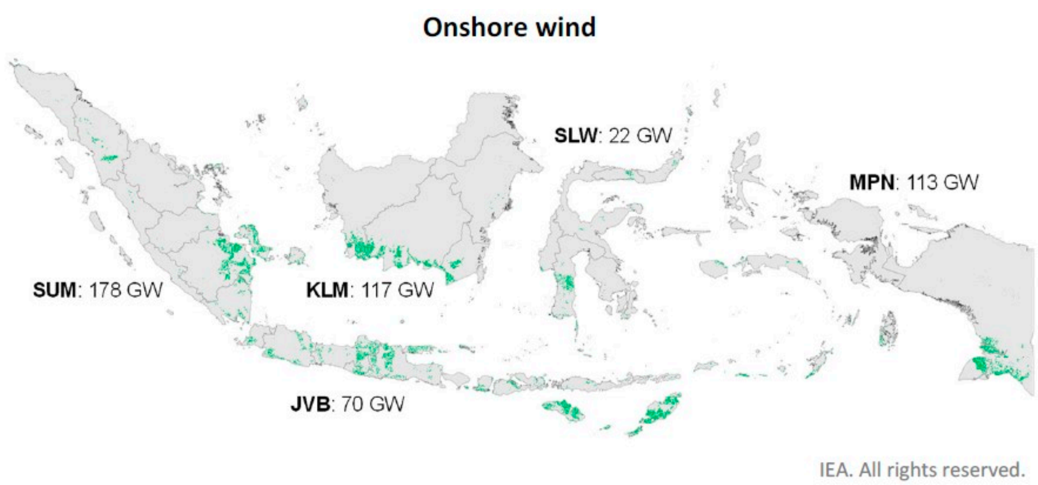

Figure 1. Indonesia wind resource map [25].

2.4. Geothermal Energy

Indonesia, situated along the Pacific Ring of Fire, is well positioned to be a world leader of geothermal energy sources [20]. In 2023, Indonesia's geothermal energy capacity reached approximately 2576 MW, positioning the country as one of the world's leading producers of geothermal power. Indonesia has identified more than 300 geothermal sites, with a combined estimated capacity of 29,000 MW [6]. This potential is also highlighted in the National Electricity Supply Business Plan (RUPTL) 2021–2030, which specifies a geothermal energy potential of 23,965 MW across various regions in Indonesia, even though most of the resources are still collocated in the regions of Sumatera and Java, as shown in Table 3. [4,17].

Table 3. Indonesia's geothermal energy potential [17].

No	Location	Energy Potential					Total
		Resources (MW)		Reserve (MW)			
		Speculative	Hypothetical	Probable	Possible	Proven	
1	Sumatera	2188	1567	3514	876	1169	9305
2	Java	1164	1270	3121	363	1855	7773
3	Bali and Nusa Tenggara	70	219	104	110	30	335
4	Kalimantan	151	18	6	-	-	182
6	Sulawesi	1352	342	99	180	120	2990
7	Maluku	560	80	496	6	2	1144
8	Papua	75	-	-	-	-	75
Total		**5775**	**3444**	**8968**	**1664**	**3210**	**23,060**

In recent years, geothermal development has been assigned a high priority in RUPTL 2021–2030 and RUEN to meet the country's 2025 renewable targets. In support of that, the government has allocated resources to support the sector through infrastructure financing for the geothermal sector, as well as fiscal incentives that are funded by the Asian Development Bank (ADB) and Green Climate Fund. This substantial resource has catalyzed the development of numerous geothermal power projects, including Sarulla (USD 250 million), Muara Laboh (USD 70 million), and Rantau Dedap (USD 173 million), showcasing Indonesia's commitment to leveraging its geothermal assets [20].

2.5. Bioenergy

Indonesia, with its vast agricultural landscape and significant biomass resources, holds considerable potential for bioenergy production, which is energy derived from organic materials, including plant and animal waste, which can be converted into bioelectricity, biogas, or biofuel, producing approximately 146.7 million tons of biomass waste in 2023 [20]. From this production, the regions with the highest potential sources include Kalimantan, Sumatera, and Sulawesi, but potential is distributed throughout the country [20]. In this case itself, the crop most supported and sought after as a commodity is palm oil due to its many available parts, like palm kernel shells, palm fiber, and empty fruit bunches, all derivatives of the palm oil production; however, there are also initiatives to produce biodiesel from corn kernel, microorganisms, etc. [6].

In 2022, Indonesia's biodiesel production reached a substantial volume of 9.68 million kL, with an allocation target of 11.02 million kL, marking a significant growth in biofuel output. This increase has driven a rise in biodiesel exports, from 28,000 kL in 2020 to

250,000 kL in 2022, indicating a strong demand within Indonesia, as illustrated in Figure 2, and is predicted to increase in the future [6]. Furthermore, the Ministry of Energy and Mineral Resources (MEMR) has accelerated the bioenergy sector development, achieving an installed bioenergy capacity of approximately 1.8 GW, which includes biogas plants, biomass power facilities, and biofuel production units. MEMR also plans to expand bioenergy production due to abundant feedstock availability, exemplified by the "Merah Putih" catalyst plant, operational since 2023, with an investment of IDR 286 billion [26].

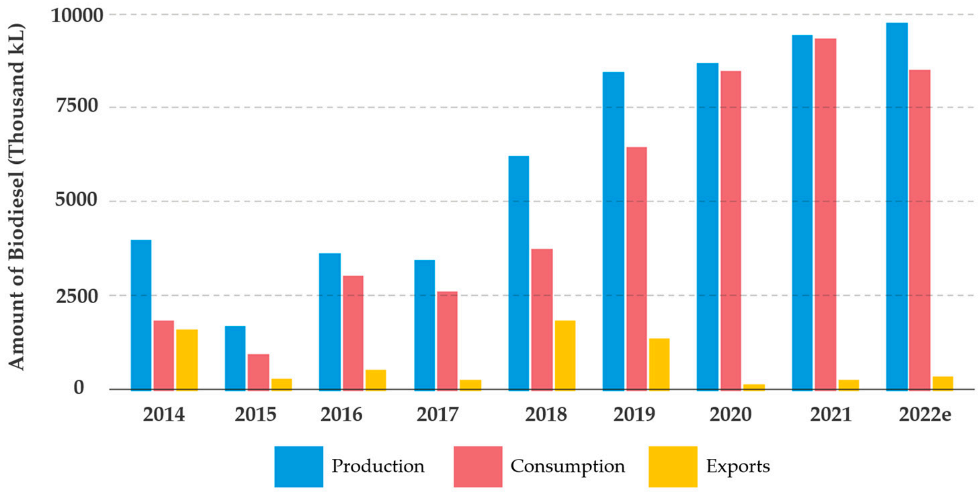

Figure 2. Biodiesel production, consumption, and exports [6].

2.6. Hydrogen Energy

Hydrogen is increasingly recognized as a vital sustainable alternative to conventional fossil fuels due to its environmentally favorable characteristics. The global hydrogen market is expected to reach USD 201 billion, with a compound annual growth rate of 9.2%, reflecting a significant upward trend in hydrogen adoption [27]. Hydrogen also demonstrates superior performance attributes, with an energy density of 142 kJ/g upon combustion, the highest among conventional fuels [8,28,29].

Supported by the achievement and the massive potential of hydrogen energies, Indonesia has started to initiate the construction of hydrogen power plants in several regions, focusing on North Sumatra, East Kalimantan, and South Sumatra, which account for 35%, 18%, and 11% of the planned capacity production [30]. Furthermore, Indonesia's government, through the National Research and Innovation Agency, collaborating with Indonesia Fuel Cell and Hydrogen Energy (IFHE), has targeted to progressively construct hydrogen power plants as much as 0.5 GW by 2030, 5 GW by 2035, 20 GW by 2040, 30 GW by 2050, and 40 GW by 2060, with the possible roadmap target shown in Figure 3, focusing on transforming Indonesia economy [31].

Currently, the key achievements in hydrogen energy in Indonesia have already been initiated by the PT PLN Nusantara Power, a subsidiary of PLN, through the operation of the first green hydrogen plant in Indonesia, at the Muara Karang Combined Cycle Power Plant, which produced 51 tons of green hydrogen in 2023, possibly marking the initiation of the green hydrogen trend [32]. In the future, it is targeted that Indonesia will utilize 1–5% of its electricity output from hydrogen sources, with 5–10% transportation using hydrogen [31].

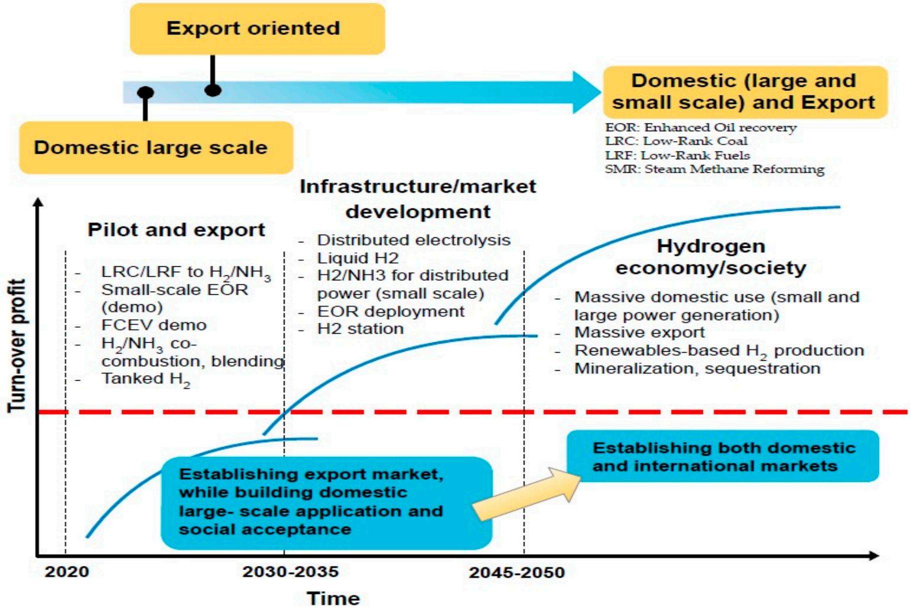

Figure 3. Phase roadmap for hydrogen energy development in Indonesia [31].

2.7. Nuclear Energy

Nuclear energy is widely recognized as a reliable and efficient alternative to traditional fuels, offering a stable energy output with minimal environmental impact, and thus is often considered a "carbon-free" source of electricity. In 2020, nuclear power accounted for approximately 10% of global electricity generation, making it the second-largest source of non-fossil electricity after hydropower and the primary source within advanced economies [33], as illustrated in Figure 4. Moreover, the global nuclear power market, valued at around USD 47 billion as of 2024, is projected to grow at a compound annual growth rate (CAGR) of 1.6%, signaling a sustained interest in nuclear energy adoption [34].

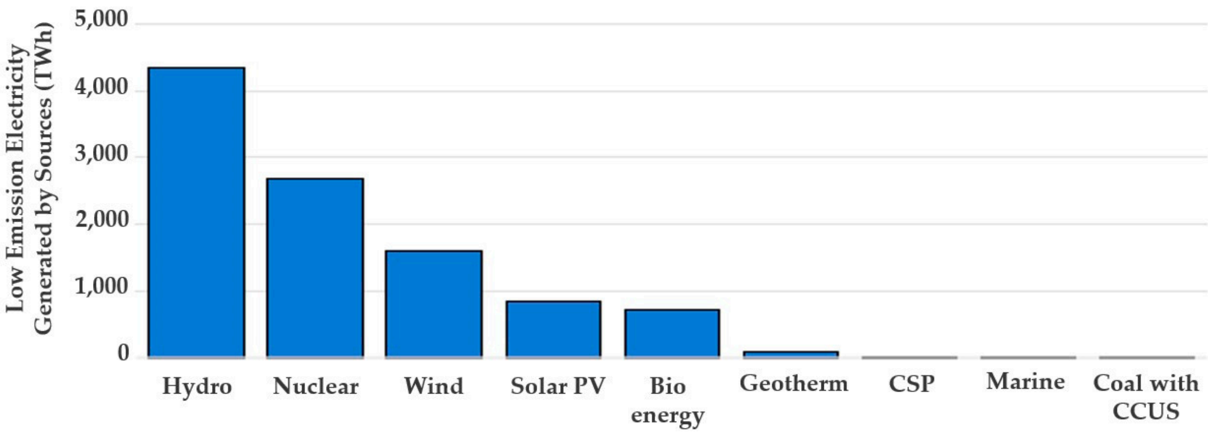

Figure 4. Worldwide low-emission electricity generation by source [33].

According to the National Electricity General Plan (RUKN), Indonesia has an estimated 4729 tons of thorium and 5234 tons of uranium available as potential nuclear fuel sources [4]. Recognizing this significant potential, Indonesia has taken initial steps toward integrating nuclear energy into its energy portfolio. In 2006, the government began evaluating the feasibility of a nuclear power program, followed by policy development in 2007 to prepare for nuclear power plant construction [35]. The MEMR has projected nuclear electricity generation to commence by 2033 as an alternative to coal-fired power generation.

The planned locations for nuclear power plants include the Muria Peninsula, Banten, Bangka Island, East Kalimantan, West Kalimantan, Batam, and West Nusa Tenggara, where feasibility studies are underway [35]. An early milestone in Indonesia's nuclear journey is the development of the G.A. Siwabessy research reactor in Serpong, intended to serve as a pilot for future nuclear projects [36]. The achievement of nuclear power in Indonesia has gained momentum under Prabowo Subianto's presidency, with collaborative initiatives underway, particularly in partnership with Russia [37].

3. Indonesia's Energy Market and Regulation Overview

Coal-fired power plants (CFPPs) have been the dominant contributor to Indonesia's electricity generation [11,13]. In 2023, CFPPs corresponded to around 54.9% of the country's plant capacity, while around 25.6% and 5.1% consist of natural gas and diesel oil, respectively, with the remainder originating from renewable energy [5]. The share portion has amounted to 85.6% of conventional energy from 90,707 MW of the total installed power plant capacities in 2023. From output perspectives, CFPPs have supplied around 67.3% of Indonesia's electricity output, coupled with 18.9% from natural gas and 2.1% from diesel oil, amounting to 88.3% output of conventional energy from the total of 322.1 TWh total output in 2023 [5]. The attributed power plant capacities and outputs are shown in Figure 5.

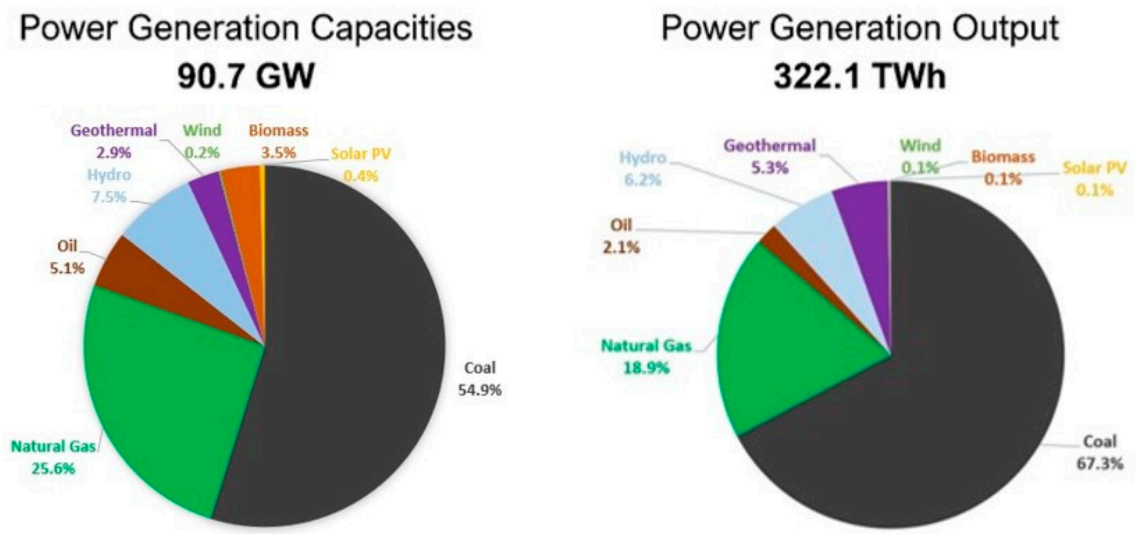

Figure 5. Indonesia power generation capacity and output in 2023 [5].

However, recent findings have found that the continuous exploitation of CFPPs is unsustainable for the environment, evident in the survey from the National Oceanic and Atmospheric Administration (NOAA), which states that the global atmospheric CO_2 amount has increased rapidly from 318 ppm in 1960 to 412.5 ppm in 2020, mainly resulting from the excess consumption of conventional fossil fuels [38]. This finding is also reflected in Indonesia's emission quantity, increasing from around 150 $MtCO_2$ in 1990 to 581 $MtCO_2$ in 2019, with the prominent contributors being the industrial (37%), power (27%), and transportation sectors (27%), with 3% consisting of other energy-related sectors (*) that covers energy related emission from processing fossil fuels, as shown in Figure 6 [9].

The massive emissions coupled with the depleting quantity of coal resources have raised concerns regarding the lack of availability and affordability, which might threaten Indonesia's energy security, forcing the government to adhere to the content of the Paris Agreement, which translates into an actionable business plan for the early retirement of CFPPs starting from 2030, as shown in Figure 7. The projections indicate that, from 49.93 GW of operating CFPPs in 2030, a gradual decommissioning will commence with

1 GW retiring in 2030, followed by 9 GW in 2035, 10 GW in 2040, 24 GW in 2045, and the remaining capacity phased out by 2055 [1,10]. This systematic reduction will drive the need for substantial renewable energy expansion to fulfill Indonesia's future energy.

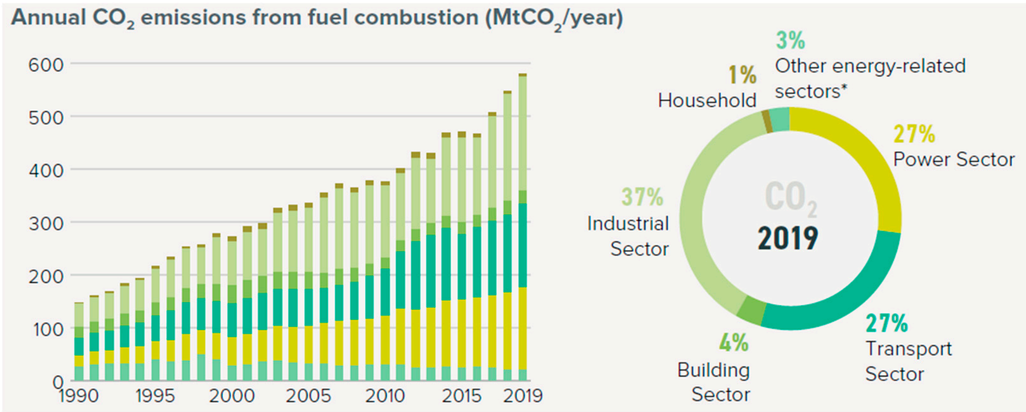

Figure 6. Annual carbon dioxide emissions according to the sector sources in 2019 [9].

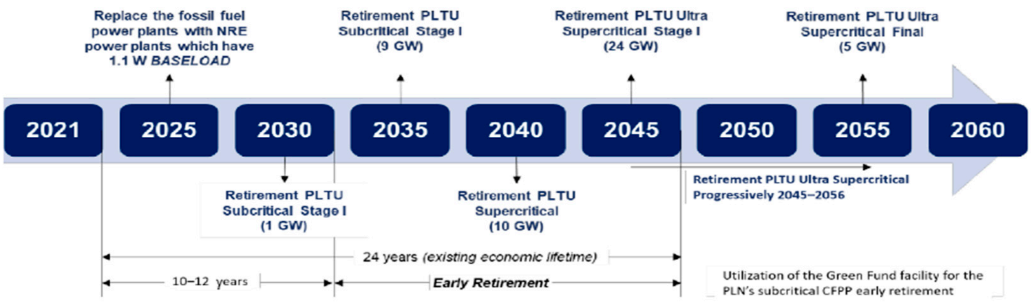

Figure 7. Indonesia business plan for providing electricity [1].

Indonesia possesses substantial renewable energy potential, estimated at a total of 441.7 GW, as detailed in Table 4, and reported by the Ministry of Energy and Mineral Resources (MEMR) in RUPTL 2021–2030 [4]. This potential spans multiple sources—including hydropower, geothermal, bioenergy, solar, wind, and ocean energies—reflecting Indonesia's rich natural resources and diverse geography [11,39]. Despite this vast potential, only around 13.1 GW, or approximately 2.97%, has been developed to date [5]. Additionally, outside of RUPTL 2021–2030, there is also the potential of utilizing hydrogen and nuclear-based energies.

Table 4. Indonesia's renewable energy potential [4,5].

Energy Source	Potential Capacity (GW)	Installed Capacity (GW)	Percentage (%)
Hydro	94.3	6.78	7.19%
Geothermal	28.5	2.60	9.11%
Biomass	32.6	3.2	9.82%
Solar Energy	207.8	0.37	0.18%
Wind	60.6	0.15	0.25%
Ocean	17.9	0	0.00%
Total	**441.7**	**13.10**	**2.97%**

Developing renewable energy within Indonesia's energy mix is crucial for addressing the country's energy trilemma, which includes ensuring energy security to reliably meet the current and future demands, promoting energy equity to provide universal access to affordable energy, and enhancing environmental sustainability to align with pressing ecological concerns [40]. The increasing urgency for renewable energy has driven the Indonesian government to introduce several groundbreaking policies aimed at advancing renewable energy development. Table 5 summarizes the evolution of Indonesia's renewable energy policies, highlighting the shifting perspectives within the country's energy landscape.

Table 5. Indonesia's regulations and roadmap for renewable energy production [4,10,14,15,19,31,41–50].

Indonesian Regulation/ Roadmap	Description	Strategy
Presidential Regulation No. 5/2006	Establishes targets to secure a sufficient domestic energy supply through a balanced mix of energy sources.	Sets a target for an optimal primary energy mix by 2025 through the diversification of conventional and renewable energy sources.
Law No. 30/2007	Provides a comprehensive legal framework for national energy policy, emphasizing energy security, sustainability, and environmental preservation.	Mandates for renewable energy transition and the diversification of energy sources, prioritizing energy efficiency and sustainability across different industry sectors.
Law No. 30/2009	Regulates the supply, distribution, and pricing of electricity to ensure a universal access to and a reliable service of electricity in Indonesia.	Promotes private sector participation in electricity generation and encourages renewable energy investments to expand Indonesia's electricity infrastructure while also providing subsidies and funds for low-income people.
Government Regulation No. 79/2014 (National Energy Policy)	Provides the objective of national energy management to achieve energy independence and national energy security to support Indonesia's sustainable landscape development.	Projects roadmap for new and renewable energy by utilizing 23% renewable electricity by 2025, 28% by 2038, and 31% by 2050, restricting conventional energy.
MEMR Regulation No. 12/2017	Provides guidelines for the utilization of renewable energy for electricity, including pricing mechanisms.	Directs PT PLN to prioritize renewable energy purchases and establishes feed-in tariffs for sources like solar, wind, and biomass to encourage adoption.
Presidential Regulation No. 22/2017 (National Energy General Plan)	Appoints the energy management plan, which constitutes the application and implementation of energy policy across sectors that are attributed to the National Energy Policy (KEN).	Develops a comprehensive policy framework from 2016 to 2050, detailing initiatives by various ministries to support national energy targets.
MEMR Regulation No. 53/2018	Provides guidelines for accelerating renewable energy adoption in the electricity sector.	Encourages local governments and the private sector to invest in renewable energy projects, simplifies permit procedures, and offers incentives to increase renewable energy adoption.
RUKN (National Electricity General Plan) 2019–2038	Lays out Indonesia's long-term electricity development strategy, with a focus on a sustainable and inclusive energy future, which consist of investment and renewable energy policies	Plans to increase the renewable share in the national energy mix, enhance grid reliability, and expand electricity access to remote areas.

Table 5. *Cont.*

Indonesian Regulation/ Roadmap	Description	Strategy
MEMR Regulation No.9/2020	Establishes efficiency targets and operational goals for PT PLN in electricity generation and distribution by providing comprehensive reporting mechanism.	PT PLN is tasked with setting and achieving efficiency targets in electricity generation and network distribution.
Government Regulations No.25/2021	Implements the Job Creation Law in the energy and mineral resources sectors, including provisions for mineral, coal, and geothermal industries.	Impose a 0% royalty policy for certain mining operations and promote geothermal projects through structured exploration and exploitation practices.
RUPTL (Electricity Supply Business Plan) 2021–2030	Details PT PLN's 10-year plan for electricity supply, including generation, distribution, and transmission.	Develops scenario-based models (moderate and optimistic) for electricity generation and supply strategies to guide Indonesia's energy infrastructure.
Presidential Regulation No. 112/2022	Reinforces Indonesia's commitment to renewable energy development by promoting investment and achieving renewable energy mix targets in line with national energy and GHG reduction policies.	Prohibits new coal-fired power plants and mandates early retirement schedules for existing plants, to be implemented by PT PLN and independent power producers (IPPs).
Indonesia's Enhanced Nationally Determined Contribution 2060	Outlines the country's transition to a low carbon and climate resilience future on several progression. By 2030, Indonesia envisions achieving archipelagic climate resilience and setting ambitious goals for sustainability. Beyond 2030, progressing towards transitioning into long-term low carbon and climate resilience development strategy.	Outlines a strategic framework with nine programs for the 2030 NDC, along with a long-term strategy for reducing greenhouse gas emissions and promoting sustainable economic activities.
Indonesia Fuel Cell and Hydrogen (IFHE)—Indonesia Hydrogen Roadmap 2023	Provides a strategic foundation for hydrogen energy development, including scenarios and application pathways for hydrogen adoption within Indonesia's energy framework.	Defines a phased approach for hydrogen power plant development, targeting 0.5 GW by 2030, 5 GW by 2035, 20 GW by 2040, and 30 GW by 2050, leveraging diverse hydrogen sources.
MEMR Regulation No. 2/2024	Enriches Indonesia's rooftop solar power plant implementation by improving efficiency and transparency while garnering public interest in installing rooftop solar power plants.	Streamlined rooftop solar power plant policy by implementing by changing stipulation regarding capacity limit, electricity export–import, and the total capacity charge for rooftop solar power plant.
Asian Development Bank Institute: Transition from Coals to Renewable Energy: Evidence from Indonesia	Quantifies and identifies challenges and constraints of Indonesia's energy transition mechanism from four aspects: national energy planning; regulatory and legal framework; technology and infrastructure; and renewable energy financing.	Outlines Indonesia's target to achieve enhanced commitment in Nationally Determined Contribution 2060 by 2030 coal-phase out policy by tackling challenges and constraints on renewable energy.

The substantial potential of Indonesia's renewable energy sector has heightened awareness domestically and globally, attracting increased financing for further development and sparking interest from multiple stakeholders. According to the International Renewable Energy Agency (IRENA) in its *Indonesia Energy Transition Outlook*, projections based on a 1.5 °C scenario and a net zero emissions target by 2050 suggest that Indonesia's energy sector will require an investment between USD 73 billion and USD 76 billion from 2018 to 2050. Specifically, from 2018 to 2030, IRENA estimates that investment needs will amount to approximately USD 44 billion for solar photovoltaics (PVs), USD 44 billion for hydropower, USD 22 billion for geothermal energy, USD 5.5 billion for grid development, and USD 15 billion for energy storage [6].

In contrast, IESR estimates that the annual investment requirements to achieve Indonesia's Nationally Determined Contribution (NDC) target of 100% renewable energy by 2060 are from around USD 20 to 25 billion from 2021 to 2030. From 2030 to 2040, this investment would need to increase to an annual USD 60 billion to accelerate carbon reduction efforts. The distribution of these investments comprises approximately USD 45.6 billion for solar PVs, USD 36.2 billion for hydropower, USD 79.1 billion for geothermal energy, USD 7 billion for energy storage, and USD 3.3 billion for biofuels/biomass waste [6]. A comparative overview of these investment projections is presented in Table 6.

Table 6. Indonesia's renewable energy investment requirement [6].

Technology	**Investment Requirement from IRENA (USD Billion)**	**Investment Requirement from IESR (USD Billion)**
Hydro	44	36.2
Geothermal	22	79.1
Solar PVs	44	45.6
Energy Storage	15	7
Grid	5.5	3.3
Biofuels/Biomass	-	2.3
Total	**130.5**	**173.5**

4. Challenges to and Opportunities for Renewable Energy Transition

4.1. Challenges to Renewable Energy Transition

The current state of Indonesia's energy sector highlights several barriers and challenges that hinder a full transition to renewable energy. A significant challenge lies in the uneven distribution of electricity infrastructure across regions. The Java–Bali grid, for example, is the most developed and reliable system in Indonesia, supporting most of the nation's population and economic activities, benefiting from greater investments, advanced infrastructure, and superior technology. In contrast, remote islands and regions face challenges in achieving a consistent and reliable electricity supply [4]. Quantitatively, the Java–Bali grid accounts for approximately 181 terawatt-hours (TWh) of electricity consumption, while Sumatra's demand is around 38 TWh, and the combined consumption for Kalimantan, Sulawesi, Maluku, and Papua reach only 24 TWh [20].

This disparity results in a technological gap outside the Java–Bali region, leading to outdated energy infrastructure and educational systems that may not adequately prepare the workforce for renewable energy development. Consequently, there are fewer opportunities to cultivate expertise in renewable energy, which poses a challenge to achieving a balanced and equitable energy transition across the country. This is evident in Indonesia's ongoing struggle to provide sufficient electricity for 25 million people, primarily in outlying islands and remote areas, where logistical challenges and sparse populations make grid-based solutions impractical [51].

In addition to the infrastructural challenges, there are significant policy barriers that hinder the implementation of renewable energy in Indonesia. One major issue is the instability of the regulatory framework, which is difficult to enforce due to inconsistencies among governing bodies. For example, the Indonesian government has struggled to meet its financing needs for expanding the renewable energy sector, resulting in an insufficient share of renewable energy (11.5%) compared to the target of 23% by 2025 outlined in the National Energy Policy, indicating the lack of regulation enactment from the governing bodies themselves [5].

Subsequently, the emerging gap from the lack of regulation enactment raises additional concerns regarding renewable energy's investment needs, whose fulfilment is urgent. Generally, the financing plan for renewable power plants mostly utilize debt financing with 4:1 debt-to-equity ratios [52]. This requires Indonesia to issue an international bond to supply an upfront investment for renewable energy projects through international collaboration. However, the lack of regulatory enactment has created a delay to or interval on renewable energy projects in Indonesia, diminishing the investors' confidence level regarsing financing Indonesia's renewable energy projects.

Furthermore, there is a notable lack of public awareness regarding renewable energy implementation, particularly in the case of nuclear energy. Currently, negative perceptions and societal skepticism toward nuclear energy persist, largely due to misinformation and inadequate public engagement [53]. These concerns are further amplified by the absence of targeted education and awareness campaigns to address safety advancements and potential benefits associated with modern nuclear technologies [53]. To overcome this challenge, it is imperative for the government to enhance public awareness and foster a more positive perception of nuclear energy, facilitating a smoother transition towards its integration into Indonesia's energy landscape.

4.2. Opportunities in Renewable Energy Transition

Transitioning to renewable energy offers significant benefits for Indonesia's economic sector, encompassing both direct and indirect advantages. Among the direct benefits, the shift to renewable energy creates substantial opportunities for job creation and local economic development. As the transition progresses, Indonesia is likely to experience changes in both the emergence of new green jobs and the adaptation of existing roles to align with sustainable practices, as mentioned in Indonesia's Enhanced Nationally Determined Contribution [43].

In 2023, approximately 40% of Indonesian companies reported having a green strategy in place; around 58% established dedicated energy teams or personnel; and 37% of surveyed companies were actively monitoring emissions from energy use. Furthermore, about 15% had already set specific targets for energy efficiency and emissions reductions [54]. These indicators suggest that, in the long term, renewable energy-related employment in Indonesia is anticipated to grow significantly, from the current 0.63 million jobs to 0.74 million by 2030 and 1.07 million by 2050, spanning manufacturing, construction, installation, operation, and maintenance of renewable energy systems [6].

Bioenergy stands out as one of Indonesia's most promising renewable energy sources, offering substantial employment potential. As the world's largest biodiesel producer, surpassing countries such as Brazil and the United States, Indonesia holds a dominant position in the global bioenergy market. This prominence is reflected in employment figures, with Indonesia accounting for approximately 555,900 jobs in the liquid biofuel sector, making it the second-largest employer globally in this field, following only Brazil with 863,000 jobs, as shown in Figure 8. Future projections suggest that an ambitious transition to renewables could significantly boost employment in the sector, with estimates indicating that renewable energy jobs could increase to about 2 million by 2030 and 2.5 million by 2050, primarily driven by the bioenergy and solar sectors [55].

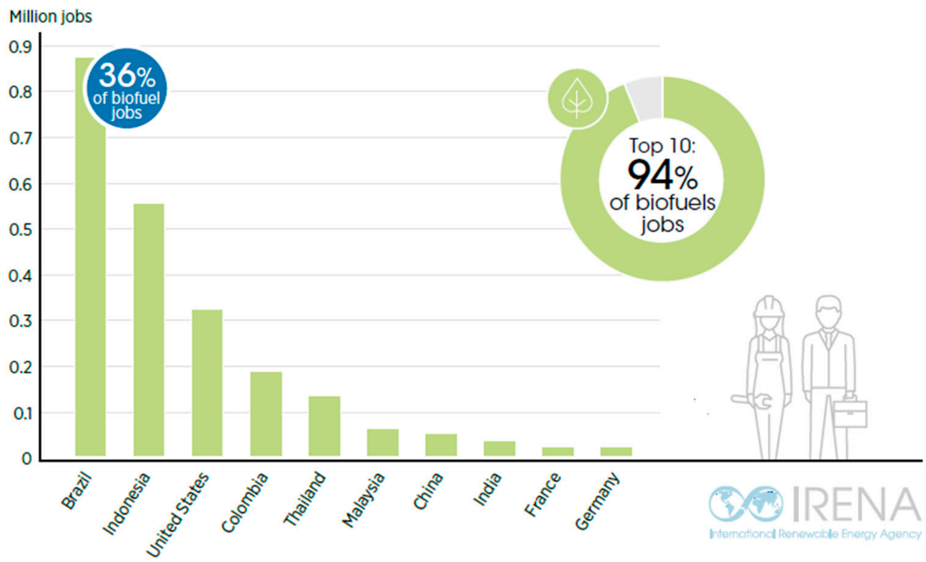

Figure 8. Liquid biofuel sector employment in Indonesia [55].

Investment in renewable energy infrastructure significantly contributes to Indonesia's economic growth, drawing substantial domestic and international interest. In 2023, foreign direct investment (FDI) in Indonesia's renewable energy sector reached USD 2.5 billion, marking a notable increase from previous years. This surge in FDI highlights Indonesia's rising status as a favorable destination for renewable energy development. Meanwhile, domestic investment in renewable energy projects amounted to approximately USD 1.8 billion during the same period, indicating a strong local interest and confidence in the sector [54]. When effectively managed, the economic impact of renewable energy investments can be amplified, where, in 2023, clean electricity accounted for 80% of new electricity additions, potentially responsible for 10% of the global GDP growth in 2023 [56].

On the contrary, the transition to renewable energy also offers substantial indirect benefits, including reductions in energy costs, enhanced energy security, increased industry competition, and significant environmental and health improvements. Firstly, the transition can lead to a notable reduction in energy costs. Renewable energy sources, such as solar, wind, and hydro, have lower operational and maintenance expenses compared to fossil fuel-based power plants. In the past decade, the costs of renewable energy technologies have significantly decreased. For example, the cost of solar photovoltaic (PV) panels has dropped by approximately 80%, while wind power costs have declined by around 40% [57]. These reductions are expected to result in lower electricity prices for both consumers and businesses, thereby stimulating economic growth by reducing household energy expenditures.

Secondly, renewable energy adoption can improve energy security by decreasing dependence on imported fossil fuels. Currently, Indonesia relies heavily on oil imports, exposing the country to fluctuations in global energy prices. By investing in renewable energy infrastructure, Indonesia can strengthen its energy security and ensure a stable and predictable energy supply. Geothermal energy, for example, represents a domestic renewable resource with considerable potential that can provide consistent power, reducing the reliance on imported fuels. In 2022, Indonesia's expenditure on oil imports amounted to approximately USD 17 billion [58]. Transitioning a portion of energy demand to locally produced renewables could potentially cut fuel costs from the current 60% to under 30% by 2030 and under 15% by 2040, as the use of coal, natural gas, and oil all decline sharply [58].

Thirdly, the shift to renewable energy can enhance competition within the energy sector. Indonesia's current electricity system is characterized by a vertically integrated structure dominated by PT PLN (Persero), which acts as the primary utility and market monopolist due to its ownership of the existing electricity infrastructure [4]. However, the expansion of renewable energy has led to a rise in the number of Independent Power Producers (IPPs) specializing in renewable technologies. This increase in market participants fosters competition, encourages innovation, and supports the development of a more diverse and resilient energy sector.

Fourth, the implementation of renewable energy can yield substantial environmental and health benefits, which translate into economic gains. Unlike conventional energy sources such as coal, oil, and natural gas—which are major carbon emitters—renewable energy technologies generate little to no greenhouse gas emissions [20]. This shift contributes to improved air quality and public health, as emphasized in Presidential Regulation No. 112 of 2022. Additionally, the reduction in greenhouse gas emissions diminishes the need for costly mitigation technologies, such as Carbon Capture, Utilization, and Storage (CCUS). CCUS technologies require significant initial capital, are energy-intensive, and demand ongoing monitoring. By investing in renewable energy, the necessity for such post-treatment methods decreases, allowing funds initially allocated to CCUS projects to be redirected toward other critical investments more pertinent to Indonesia's sustainable development [6].

The key factor for achieving these economic benefits, both direct and indirect is the collaboration between the public and private sectors. Public–private partnerships (PPPs) have been instrumental in facilitating investment and innovation within the renewable energy industry. The Indonesian government has introduced various policies and incentives to attract private sector participation. These include tax incentives, subsidies, and simplified regulatory procedures for renewable energy projects. This favorable regulatory environment has successfully encouraged numerous private companies to invest in renewable energy infrastructure, fostering further development in renewable energy.

4.3. Suggested Policy Roadmap for Renewable Energy Transition

The ongoing transition to renewable energy, alongside the 2030 coal phase-out initiatives, underscores the need for Indonesia to establish a comprehensive roadmap to meet these targets. As previously mentioned, Indonesia has an estimated 441.7 GW of renewable energy potential distributed across its numerous islands, necessitating feasibility analyses to prioritize regions with the highest development potential for effective resource allocation [59]. Hydropower projects should focus on areas like Sumatra, Kalimantan, and Papua, where significant untapped hydropower capacity exists. Geothermal resources, abundant in volcanic regions such as Java, Bali, and Sumatra, should also be prioritized. For solar and wind energies, the eastern regions, including Nusa Tenggara and Sulawesi, known for high solar radiation and wind potential, are optimal targets [4].

Additionally, feasibility studies are crucial for recently proposed renewable sources, such as hydrogen and nuclear energy. Integrating hydrogen into Indonesia's energy strategy could diversify energy sources, reduce coal dependency, and align with global decarbonization efforts. However, considerable investment in infrastructure, technology, and research is necessary to enhance hydrogen's feasibility and cost-effectiveness, as its implementation in Indonesia is still in its early stages. Conversely, nuclear energy requires rigorous feasibility assessments, focusing on factors such as safety and environmental impact, given the potential risks of radioactive exposure if preventive measures are not adequately enforced. The proximity of nuclear plants to major energy demand centers must also be carefully evaluated. In the long term, Indonesia may benefit from a more integrated electricity system, addressing the energy equity aspect of the energy trilemma.

The implementation plan emphasizes the pivotal role of key stakeholders. The Ministry of Energy and Mineral Resources (MEMR) is expected to play a central role in establishing a regulatory framework by formulating policies, such as enforcing carbon emission reductions, offering incentives to stimulate investments in renewable energy, and raising public awareness about the urgency and benefits of the energy transition.

Moreover, the private sector, including energy companies and investors, is crucial for financing and constructing new energy infrastructure. Collaborations with international partners, particularly those with advanced hydrogen and nuclear energy capabilities, will be essential to provide Indonesia with technical expertise and financial support. Through this comprehensive implementation plan, Indonesia can achieve its energy transition objectives. By strategically combining renewable energy, nuclear power, and targeted investments, the nation can secure a sustainable, secure, and efficient energy future. The culmination of these efforts is outlined in the proposed policy roadmap presented in Table 7.

Table 7. Indonesia's renewable energy investment requirements.

Time Frame	Planned Roadmap
Now–2030	• Continuing planned RUPTL power plant construction with the current targeted renewable business. • Pre-feasibility studies of hydrogen power plants. • Pre-feasibility studies of nuclear power plants. • Establish a new flagship regulatory roadmap overseeing the renewable energy business. • Establish coordinated governance structure and enactment agent for renewable energy business. • Boosting fiscal policies such as tariff discounts, tax exemptions, and tax holidays while initiating energy financing with local or international collaborators. • Raising social awareness of local communities and business. • Gradual progress on coal power plant decommissioning.
2031–2040	• Ramping up contribution of renewable energy, mainly solar and hydropower. • Increased implementation of decommissioning and banning CFPPs. • Sites planning for pioneering nuclear power plants. • Starting the operation of nuclear power plants. • Fully implement carbon tax and pricing regulations. • Supporting regulation on hydrogen fuel vehicle and its refilling station development. • Initiating hydrogen export to other countries. • Encouraging competition inside the renewables landscape.
2041–2060	• Integrate hydrogen economy nationwide across several industries. • Completely decommission all coal power plants. • Large-scale production of nuclear power plants. • Maintaining the renewables economy.

5. Conclusions

Indonesia's current energy sector is heavily dependent on coal, which remains the primary energy source. Efforts to transition toward renewable energy are constrained by several challenges, including disparities in energy access, insufficient policy implementation, and unreliable government financing mechanisms. However, Indonesia has substantial renewable energy potential, particularly in hydropower, geothermal, bioenergy, solar, and wind, with emerging prospects for hydrogen and nuclear energy. To harness these opportunities effectively, there is a pressing need for the government to establish a robust policy framework and ensure all necessary conditions are in place to support the targeted energy transition.

This study highlights the current progress in Indonesia's energy landscape while identifying the obstacles and opportunities for accelerating renewable energy development. Although the existing regulatory strategies are progressive and broadly supportive of renewable energy, their implementation has been inadequate. A comprehensive policy framework is critical to realizing Indonesia's renewable energy potential. The proposed framework focuses on strengthening governance, fostering collaborations, and securing financing, while also offering tax incentives and other financial benefits for renewable energy production. Additionally, it is essential to conduct pre-feasibility studies and regional testing for emerging renewable sources to accurately account for potential risks.

For a successful transition to a renewable-based energy system, future research should prioritize the integration of Indonesia's rich renewable resources into the existing energy network. This involves conducting in-depth feasibility assessments of new renewable sources like hydrogen and nuclear, particularly in promising regions. Advanced energy storage technologies, such as hydrogen storage, should be explored to mitigate intermittency and enhance grid stability. Furthermore, studies on the socio-economic impacts of renewable energy adoption—encompassing job creation, community involvement, and capacity building—will be crucial. The government's involvement in facilitating public–private partnerships, promoting technology transfer, and developing a skilled renewable energy workforce will play a pivotal role in ensuring a sustainable and effective energy transition in Indonesia.

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References

1. EGA Indonesia. *Indonesia Economic Outlook 2023*; EGA Indonesia: Jakarta, Indonesia, 2023.
2. PwC Indonesia. *PwC Indonesia Economic Update: First Quarter of 2024*; PwC Indonesia: Jakarta, Indonesia, 2024.
3. PLN. *PLN 2023 Annual Report—Accelerating Digital Technology and Strengthening Inclusive and Sustainable Transformation*; PLN: Jakarta, Indonesia, 2023.
4. PLN. *Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) PT PLN (Persero) 2021–2030*; PLN: Jakarta, Indonesia, 2021.
5. MEMR. *Handbook of Energy & Economic Statistics of Indonesia 2024*; MEMR: Jakarta, Indonesia, 2024.
6. IESR. *Indonesia Energy Transition Outlook 2023: Tracking Progress of Energy Transition in Indonesia: Pursuing Energy Security in the Time of Transition*; IESR: Jakarta, Indonesia, 2022.
7. Hakam, D.F. Mitigating the Risk of Market Power Abuse in Electricity Sector Restructuring: Evidence from Indonesia. *Util. Policy* **2019**, *56*, 181–191. [CrossRef]
8. Wijayanto, T.; Hakam, D.F.; Kemala, P.N. Vision for Indonesia's 2050 Power Generation: Scenarios of Hydrogen Integration, Nuclear Energy Prospects, and Coal Phase-out Impact. *Sustain. Futur.* **2025**, *9*, 100438. [CrossRef]
9. Climate Transparency. *Indonesia Climate Transparency Report—Comparing G20 Climate Action and Responses to the COVID-19 Crisis*; Climate Transparency: Jakarta, Indonesia, 2020.
10. Sujai, M.; Wahyudi, R.; Sakina, N.A. *Transition from Coals to Renewable Energy: Evidence from Indonesia*; Asian Development Bank Institute: Jakarta, Indonesia, 2023.

11. Kanugrahan, S.P.; Hakam, D.F. Long-Term Scenarios of Indonesia Power Sector to Achieve Nationally Determined Contribution (NDC) 2060. *Energies* **2023**, *16*, 4719. [CrossRef]
12. Pramana, P.A.A.; Hakam, D.F.; Tambunan, H.B.; Tofani, K.M.; Mangunkusumo, K.G.H. How Are Consumer Perspectives of PV Rooftops and New Business Initiatives in Indonesia's Energy Transition? *Sustainability* **2024**, *16*, 1590. [CrossRef]
13. Kanugrahan, S.P.; Hakam, D.F.; Nugraha, H. Techno-Economic Analysis of Indonesia Power Generation Expansion to Achieve Economic Sustainability and Net Zero Carbon 2050. *Sustainability* **2022**, *14*, 9038. [CrossRef]
14. Indonesia Government. *Government Regulation No 79/2014 on National Energy Policy*; Indonesia, 2014; pp. 1–203. Available online: https://policy.asiapacificenergy.org/node/3016 (accessed on 8 January 2025).
15. Presidential Regulation. Presidential Regulation. Indonesia, 2017. Available online: https://peraturan.bpk.go.id/Details/68772 (accessed on 8 January 2025).
16. Tambunan, H.B.; Hakam, D.F.; Prahastono, I.; Pharmatrisanti, A.; Purnomoadi, A.P.; Aisyah, S.; Wicakson, Y.; Sandy, I.G.R. The Challenges and Opportunities of Renewable Energy Source (RES) Penetration in Indonesia: Case Study of Java-Bali Power System. *Energies* **2020**, *13*, 5903. [CrossRef]
17. MEMR. *Technology Data for the Indonesian Power Sector*; MEMR: Jakarta, Indonesia, 2024.
18. Bappenas. *Green Recovery Roadmap Indonesia 2021–2024*; Bappenas: Jakarta, Indonesia, 2021.
19. Menteri ESDM. *Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 2 Tahun 2024 Tentang Pembangkit Listrik Tenaga Surya Atap Yang Terhubung Pada Jaringan Tenaga Listrik Pemegang Izizn Usaha Penyediaan Tenaga Listrik Untuk Kepentingan Umum*; MEMR Regulation; Menteri ESDM: Jakarta, Indonesia, 2024; Volume 2024, pp. 1–35. Available online: https://jdih.esdm.go.id/index.php/web/result/2428/detail (accessed on 8 January 2025).
20. ADB. *Energy Sector Assessment, Strategy, and Road Map: Indonesia*; Asian Development Bank: Manila, Philippines, 2020; ISBN 9789292575137.
21. World Water Forum. Indonesia Launched Its First Floating Solar Power Plant in Cirata Reservoir, the Largest in Southeast Asia. Available online: https://worldwaterforum.org/blog/news-3/indonesia-launched-its-firstfloating-solar-power-plant-in-cirata-reservoir-the-largest-in-southeast-asia-89 (accessed on 21 November 2024).
22. Rosyidah, U.; Raihan, D.; Kurniawan, T. Impact Analysis of Integrated Waste Management Program on Reducing Sedimentation of Saguling Reservoir by PT. PLN Indonesia Power UBP Saguling. *Int. J. Sci. Soc.* **2024**, *6*, 438–452.
23. Ardiansyah, H. Hydropower Technology: Potential, Challenges, and the Future. In *Indonesia Post-Pandemic Outlook: Strategy towards Net-Zero Emissions by 2060 from the Renewables and Carbon-Neutral Energy Perspectives*; BRIN Publishing: Jakarta, Indonesia, 2022; pp. 89–107. [CrossRef]
24. Hidayat, T. Wind Power in Indonesia: Potential, Challenges, and Current Technology Overview. In *Indonesia Post-Pandemic Outlook: Strategy towards Net-Zero Emissions by 2060 from the Renewables and Carbon-Neutral Energy Perspectives*; BRIN Publishing: Jakarta, Indonesia, 2022; pp. 109–132. [CrossRef]
25. OECD. *Southeast Asia Energy Outlook 2022*; OECD: Paris, France, 2022. [CrossRef]
26. Elvira, V. Pabrik Katalis Merah Putih Resmi Berproduksi, Kapasitas Hingga 800 ton per Tahun. Available online: https://industri.kontan.co.id/news/pabrik-katalis-merah-putih-resmi-berproduksi-kapasitas-hingga-800-ton-per-tahun (accessed on 20 November 2024).
27. Spherical Insight. *Asia Pacific Hydrogen Generation Market Size, Share, and COVID-19 Impact Analysis, by Source (Natural Gas, Coal, Biomass, Water), by Process (Steam Methane Reforming, Coal Gasification, Electrolysis, Others), by Application (Methanol Production, Ammonia P)*; Spherical Insight: Mason, OH, USA, 2023.
28. Yadav, M.; Paritosh, K.; Vivekanand, V. Lignocellulose to Bio-Hydrogen: An Overview on Recent Developments. *Int. J. Hydrogen Energy* **2020**, *45*, 18195–18210. [CrossRef]
29. Sekoai, P.T.; Chunilall, V.; Ezeokoli, O. Creating Value from Acidogenic Biohydrogen Fermentation Effluents: An Innovative Approach for a Circular Bioeconomy That Is Acquired via a Microbial Biorefinery-Based Framework. *Fermentation* **2023**, *9*, 602. [CrossRef]
30. Deloitte. *Green Hydrogen: Energizing the Path to Net Zero*; Deloitte: London, UK, 2023.
31. IFHE. *Indonesia Hidrogen Roadmap*; IFHE: Jakarta, Indonesia, 2023.
32. PLN. *Green Hydrogen Business PT PLN (Persero)*; PLN: Jakarta, Indonesia, 2024.
33. IEA. *Nuclear Power and Secure Energy Transitions*; IEA: Paris, France, 2022.
34. Statista Nuclear Power—Worldwide. Available online: https://www.statista.com/outlook/io/energy/nuclear-power/worldwide (accessed on 20 November 2024).
35. Suparman, S. *Nuclear Power Program in Indonesia: Potential and Challenges*; Badan Tenaga Nuklir Nasional (BATAN): Jakarta, Indonesia, 2020; pp. 24–27.
36. The Jakarta Post Indonesia's Nuclear Horizon: Diplomatic Finesse Needed. Available online: https://www.thejakartapost.com/opinion/2024/07/06/indonesias-nuclear-horizon-diplomatic-finesse-needed.html (accessed on 20 November 2024).

37. Nikkei Asia Indonesia's Prabowo Asks Russia for Help to Develop Nuclear Power. Available online: https://asia.nikkei.com/Politics/International-relations/Indonesia-s-Prabowo-asks-Russia-for-help-to-develop-nuclear-power (accessed on 17 September 2024).
38. Lindsey, R. Climate Change: Atmospheric Carbon Dioxide. Available online: https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide (accessed on 20 November 2024).
39. Hasan, M.H.; Mahlia, T.M.I.; Nur, H. A Review on Energy Scenario and Sustainable Energy in Indonesia. *Renew. Sustain. Energy Rev.* **2012**, *16*, 2316–2328. [CrossRef]
40. Sumarno, T.; Wagner, J.; Weibelzahl, M.; Heffron, R.J.; Körner, M.-F.; Fridgen, G. How Different Electricity Pricing Systems Affect the Energy Trilemma: Assessing Indonesia's Electricity Market Transition. *Energy Econ.* **2022**, *107*, 105663. [CrossRef]
41. Indonesia, Pemerintah Pusat. *Percepatan Pengembangan Energi Terbarukan untuk Penyediaan Tenaga Listrik*; Presidential Regulation; Indonesia, Pemerintah Pusat: Jakarta, Indonesia, 2022; pp. 1–37. Available online: https://peraturan.bpk.go.id/Details/225308/perpres-no-112-tahun-2022 (accessed on 8 January 2025).
42. Minister of Energy and Mineral Resources of the Republic of Indonesia. *Perubahan Atas Peraturan Menteri Energi Dan Sumber Daya Mineral Nomor 50 Tahun 2017 Tentang Pemanfaatan Sumber Energi Terbarukan Untuk Penyediaan Tenaga Listrik*; MEMR Regulation; Indonesia, Kementerian Energi dan Sumber Daya Mineral: Jakarta, Indonesia, 2018. Available online: https://peraturan.bpk.go.id/Details/142954/permen-esdm-no-53-tahun-2018 (accessed on 8 January 2025).
43. Indonesia Government. *Enhanced Nationally Determined Contribution Republic of Indonesia*; Indonesia Government: Jakarta, Indonesia, 2022; Volume 11.
44. MEMR. *Rencana Umum Ketenagalistrikan Nasional 2019–2038*, 1st ed.; Pramudya, Ed.; Direktorat Jenderal Ketenagalistrikan: Jakarta, Indonesia, 2019; ISBN 9786239720520.
45. Minister of Energy and Mineral Resources of the Republic of Indonesia. *Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 9 Tahun 2020 tentang Efisiensi Penyediaan Tenaga Listrik PT Perusahaan Listrik Negara (Persero)*; MEMR Regulation; Kementerian Energi dan Sumber Daya Mineral (KESDM): Jakarta, Indonesia, 2020. Available online: https://jdih.esdm.go.id/index.php/web/result/2041/detail (accessed on 8 January 2025).
46. Indonesia, Pemerintah Pusat. *Penyelenggaraan Bidang Energi dan Sumber Daya Mineral*; Indonesia Regulation; Indonesia, Pemerintah Pusat: Jakarta, Indonesia, 2021; p. 161855. Available online: https://peraturan.bpk.go.id/Details/161855/pp-no-25-tahun-2021 (accessed on 8 January 2025).
47. President of the Republic of Indonesia. *INDONESIA: National Energy Policy 2006 (Presidential Regulation No. 5/2006 of 2006)*; Presidential Regulation; President of the Republic of Indonesia: Jakarta, Indonesia, 2006; Volume 4, pp. 25A–27A. Available online: https://policy.asiapacificenergy.org/node/3297 (accessed on 8 January 2025).
48. Indonesia Government. *Indonesia Regulation No.30/2007 Regarding Energy*; Indonesia, 2007. Available online: https://policy.asiapacificenergy.org/node/3027 (accessed on 8 January 2025).
49. Indonesia Government. *Indonesia Regulation No.30/2009 Regarding Electricity*; Indonesia, 2009; p. 43. Available online: https://policy.asiapacificenergy.org/node/3022 (accessed on 8 January 2025).
50. Minister of Energy and Mineral Resources of the Republic of Indonesia. *MEMR Regulation*; Minister of Energy and Mineral Resources of the Republic of Indonesia: Jakarta, Indonesia, 2017.
51. Setyowati, A.B. Mitigating Inequality with Emissions? Exploring Energy Justice and Financing Transitions to Low Carbon Energy in Indonesia. *Energy Res. Soc. Sci.* **2021**, *71*, 101817. [CrossRef]
52. PwC Indonesia. *Power in Indonesia: Investment and Taxation Guide 2023*; PwC Indonesia: Jakarta, Indonesia, 2023.
53. Sugiawan, Y.; Managi, S. Public Acceptance of Nuclear Power Plants in Indonesia: Portraying the Role of a Multilevel Governance System. *Energy Strateg. Rev.* **2019**, *26*, 100427. [CrossRef]
54. World Bank Group. *Indonesia Country Climate and Development Report*; World Bank Group: Jakarta, Indonesia, 2023.
55. IRENA and ILO. *Renewable Energy and Jobs: Annual Review 2022*; International Renewable Energy Agency, Abu Dhabi and International Labour Organization: Geneva, Switzerland, 2022; ISBN 978-92-9260-364-9/9164468062.
56. IEA. Clean Energy Is Boosting Economic Growth. Available online: https://www.iea.org/commentaries/clean-energy-is-boosting-economic-growth (accessed on 29 January 2025).
57. Roser, M. Why Did Renewables Become so Cheap so Fast? Available online: https://ourworldindata.org/cheap-renewables-growth (accessed on 20 November 2024).
58. IEA. *An Energy Sector Roadmap to Net Zero Emissions in Indonesia*; International Energy Agency Special Report; IEA: Paris, France, 2022.
59. DEN. *Indonesia Energy Outlook 2019*; DEN: Jakarta, Indonesia, 2019.