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REVIEW ARTICLE

An overview of the energy segment of Indonesia: present situation, prospects, and forthcoming advancements in renewable energy technology

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Abstract
The rising usage of fossil fuels increases greenhouse gas (GHG) emissions, leading to global climate change. Thus, addressing global environmental challenges requires a widespread switch from fossil fuels to renewable energy. Renewable energy reduces GHG emissions, extreme weather, and climate change while boosting energy efficiency. Indonesia ranks among Asia-Pacific's top five renewable energy producers. Indonesia, a vast country with abundant natural resources, has seen a rise in renewable energy demand as consumption has increased. Thus, this study examines Indonesia's renewable and sustainable energy technologies' existing position, possibilities, and future improvements. With 420 gigawatts (GW) of theoretical renewable energy capacity, Indonesia has great potential. This capacity includes 208 GW of solar, 75 GW of hydro, 61 GW of wind, 33 GW of biofuel, 24 GW of geothermal, and 19 GW of micro-hydro. The need to increase renewable energy consumption in Indonesia is driven by environmental and economic growth laws. This review study is expected to guide future research on renewable energy technology in Indonesia. This study would guide energy-related policies, particularly renewable energy ones, to meet future demands and goals.

Keywords: Energy consumption; Renewable energy; Emission reduction; Energy efficiency; Sustainability

Introduction

Energy plays a significant role in the developmental processes of both social and environmental aspects, hence providing support to the national economy (Raihan et al., 2022a; Voumik et al., 2022; Ghosh et al., 2023; Xing et al., 2023). In addition, energy has a crucial role in driving multiple areas of society, including technology, information, agriculture, education, health, and transportation (Raihan & Voumik, 2022a; Woo & Whale, 2022; Raihan & Tuspekova, 2023a). The energy demand is experiencing a significant increase over time, in accordance with the growth of both the economy and population (Raihan & Voumik, 2022b; Chien et al., 2023; Raihan & Tuspekova, 2023b). According to the World Bank (2023), there has been a significant increase in global energy consumption since 1971, approximately tripling in order to meet the continuously growing energy needs. The escalating utilization of fossil fuels, including coal, oil, and natural gas, exerts a substantial influence on the amplification of GHG emissions, predominantly carbon dioxide (CO_2), hence contributing to the phenomenon of global warming and climate change (Raihan et al., 2019; Begum et al., 2020; Jaafar et al., 2020; Raihan et al., 2021a; Li et al., 2022; Sultana et al., 2023; Voumik et al., 2023a). In addition, it is important to note that fossil fuel energy is non-renewable, leading to a gradual decline in its availability (Raihan & Tuspekova, 2022a; Raihan et al., 2022b; Raihan et al., 2023a). Hence, the accessibility of sustainable energy plays a crucial role in upholding sustainable development (Raihan & Tuspekova, 2022b; Raihan et al., 2022c; Raihan et al., 2023b). The use of renewable energy sources presents a viable and advantageous substitute for fossil fuels, which encounters significant opposition within the energy markets (Raihan & Tuspekova, 2022c; Raihan et al., 2022d; Donald et al., 2022; Raihan et al., 2023c). It is anticipated that the energy sector will see future expansion, prompting a transition towards renewable energy sources (Raihan & Tuspekova, 2022d; Ullah et al., 2022; Sharif et al., 2023). This transition is expected to contribute to the mitigation of GHG emissions by mitigating the adverse effects of extreme weather events and climate change (Raihan & Tuspekova, 2022e; Raihan et al., 2022e; Raihan, 2023a). Additionally, the adoption of renewable energy sources will ensure the provision of energy that is both dependable and economically viable (Wang et al., 2021; Raihan & Tuspekova, 2022f; Raihan et al., 2022f; Raihan, 2023b).

The utilization of renewable energy sources has the potential to establish a more environmentally sustainable energy framework in comparison to the reliance on fossil fuels (Raihan & Tuspekova, 2022g; Raihan et al., 2022g; Umar et al., 2022; Raihan, 2023c). Numerous countries are actively engaged in efforts to tackle climate and environmental change through the enhancement of energy efficiency and the broadening of accessibility to renewable energy sources (Aleluia et al., 2022; Raihan & Tuspekova, 2022h; Raihan, 2023d). The demand and potential for renewable energy have experienced substantial development primarily as a result of the enormous increase in global energy consumption (Luderer et al., 2022; Raihan & Tuspekova, 2022i; Raihan, 2023e). Renewable energy sources such as wind, geothermal heat, solar power, biofuel, and hydropower have garnered significant attention in several policy papers and empirical research studies due to their crucial role in mitigating energy challenges and environmental degradation (Sharif et al., 2020; Shoukat et al., 2021; Muhammad et al., 2022; Ullah & Sharif, 2022). This initiative also aligns with the pursuit of Sustainable Development Goal 7 (SDG7), which encompasses the objectives of ensuring accessible and clean energy, as well as mitigating carbon dioxide emissions (Raihan & Tuspekova, 2022j; Raihan, 2023f). Furthermore, the aforementioned endeavors influence state policies about the achievement of a sustainable environment via the utilization of renewable energy, promotion of economic activities, and facilitation of trade freedom (Santika et al., 2020; Raihan & Tuspekova, 2022k; Raihan, 2023g). The reduction of emissions through the use of renewable energy sources can be achieved by implementing poverty alleviation efforts, which hold significant importance in developing nations such as Indonesia (Setyowati, 2021).

In the preceding thirty years, Indonesia has largely depended on energy consumption as a means to propel its swift economic growth (Farabi et al., 2019). Nevertheless, at present, the Indonesian economy faces significant challenges in mitigating the extensive reliance on fossil fuels for energy generation and the resulting environmental degradation (Yana et al., 2022). Indonesia is currently facing pressure from the international community to effectively tackle the challenges associated with the increasing levels of GHG emissions (Puspitaloka et al., 2021). According to Raihan et al. (2022h), Indonesia has articulated its commitment to pursuing ambitious objectives and implementing policies aimed at mitigating the reliance on fossil fuel energy by promoting the utilization of alternative renewable energy sources. The ultimate aim of these efforts is to foster sustainable growth within the country (Raihan et al., 2023d). Figures 1 and 2 illustrate the ongoing reliance of Indonesia on fossil fuels, despite its efforts to transition towards the utilization of renewable energy sources. The transition is achieved through a gradual increase in the proportion of renewable energy sources in the overall energy mix. According to Tambunan et al. (2020), the percentage of renewable energy is projected to rise from 11% in 2021 to 23% in 2025 and further to 31% in 2050. According to Karakurt and Aydin (2023), there is a projected decline in the percentage of fossil energy mix, despite an increase in the demand for primary fossil energy supply. According to a study conducted by Gunawan et al. (2022), coal remained the primary source of energy generation in Indonesia in the year 2021.

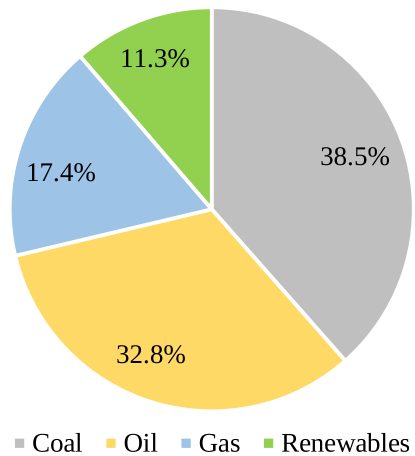

Figure 1. Indonesia's major energy sources (NEC, 2021).

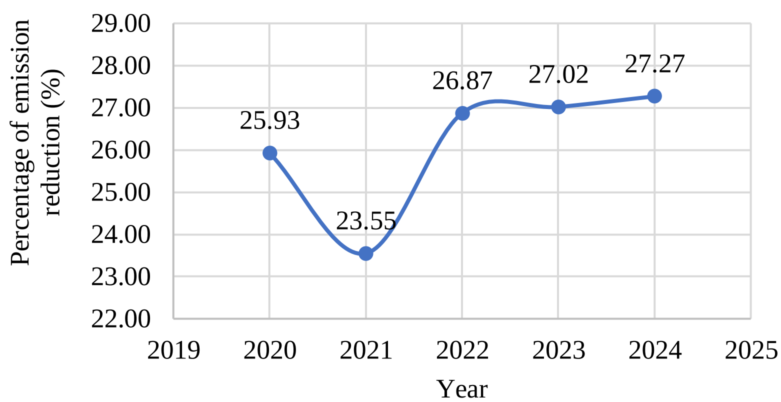

Figure 2. Indonesia's GHG emissions reduction Projection (PRRI, 2021).

According to the PRRI (2021), Indonesia achieved a reduction of 25.93% in its GHG emissions in 2020. However, in 2021, this reduction was reduced to 23.55%. Hence, it is imperative to effectively implement low-carbon development measures in the next years through the augmentation of government initiatives and financial allocations (Tiawon & Miar, 2023). Potential strategies to address environmental concerns include reforestation, the prevention of deforestation, the augmentation of renewable energy capacity, and the enhancement of energy efficiency (Raihan et al., 2018; Raihan et al., 2021b; Ali et al., 2022; Isfat & Raihan, 2022; Raihan & Said, 2022; Raihan, 2023h). Hence, it is imperative to align the restoration of economic and social activities, especially in the aftermath of the COVID-19 pandemic, with endeavors aimed at mitigating GHG emissions (Raihan & Himu, 2023; Raihan, 2023i; Zhang et al., 2023). Multiple nations, including Indonesia, have enhanced their global collaboration efforts to enable the acquisition of clean, renewable, and efficient energy technology (Raihan et al., 2022h). According to the World Bank (2023), Indonesia is positioned within the top five countries in the Asia-Pacific region in terms of its renewable energy capability. The imperative to enhance the demand for renewable energy in Indonesia

is stipulated by multiple legislative measures aimed at safeguarding the environment and fostering sustainable economic development (Raihan et al., 2023d).
As per the Indonesian Ministry of Energy and Mineral Resources, the government has become a participant in the Clean Energy Demand Initiative (CEDI). This approach serves as a means of bolstering the global community's efforts to enact climate change mitigation measures and enhance the sustainability of the economy. Hence, the implementation of the president's instructions pertaining to the Comprehensive Environmental Development Initiative (CEDI) is imperative in expediting the requisite measures for attaining the nationally determined contribution (NDC) and net zero emissions (NZE) objectives, set for the years 2030 and 2060 correspondingly. The promotion and strengthening of Indonesia's renewable energy transformation policies will be emphasized. In addition, the organization possesses a clear vision and goal to attain a 23% share of renewable energy in the primary energy composition by the year 2025. This objective is accompanied by a corresponding reduction in emissions ranging from 29% to 41% (Santika et al., 2020).
Indonesia possesses considerable potential for renewable energy, hence necessitating its future optimization (Yana et al., 2022). However, there is limited research highlighting the future potential of renewable energy in Indonesia. There is a research gap between the current status, potential, and future development of renewable energy technologies in the context of Indonesia. Hence, the objective of this study is to critically explore the current state, prospects, and forthcoming advancements in renewable and sustainable energy technologies within the context of Indonesia. The novelty of this study lies in the incorporation of the most recent data pertaining to the accessibility of renewable energy sources in Indonesia. This review aims to depict a visual representation of its prospective advancement in the forthcoming years. This review study fills up a research gap in the existing literature by providing a valuable resource for future research endeavors and enhancing understanding of the capabilities of renewable energy technologies, with a specific focus on the Indonesian setting. This study would provide valuable insights for the implementation of energy-related policies, particularly those focused on renewable sources, with the aim of addressing future needs and goals.

Methodology

The present study used the systematic literature review method to explore the energy segment of Indonesia with a focus on the present situation, prospects, and forthcoming advancements in renewable energy technology. Following the selection of the research topic, this study proceeded to identify and locate pertinent articles, conduct an analysis and synthesis of various literature sources, and compile written materials for the purpose of article review. The synthesis phase involved the gathering of diverse articles that were afterward compiled into conceptual or empirical analyses that were pertinent to the completed research.

Current Status of Indonesia's Energy Sources

The nation of Indonesia possesses a substantial abundance of natural resources that can be utilized for the purpose of energy production, either through direct utilization or by means of a conversion process (Raihan et al., 2023d). The energy mix comprises both non-renewable fossil fuel sources, including oil, gas, and coal, and renewable sources such as hydro, geothermal, mini- and micro-hydro, solar, wind power, nuclear, and various others (Raihan et al., 2022h). Certain sources have the potential to undergo processing in order to meet the requirements of the community, and the management should consult the principles of sustainable development as outlined by Litvinenko et al. (2022). The energy balance in Indonesia has undergone consistent fluctuations throughout the years. The primary energy supply, excluding biomass, experienced a notable rise from 170 million tonnes of oil equivalent

(TOE) in 2015 to 202 million TOE in 2020, exhibiting an average annual growth rate of 3.5%. In the year 2020, the overall energy production amounted to 443 million tons of oil equivalent (TOE), with fossil fuels, namely oil, gas, and coal, accounting for 95% of this production (NEC, 2021).

At present, fossil fuels continue to hold a significant proportion of the overall consumption of final energy. These resources are widely distributed over many regions, encompassing the islands of Sumatra, Java, and Kalimantan. The estimated quantity of oil reserves stands at around 4.17 billion barrels, out of which 2.44 billion barrels have been designated as reserved. In the present context, it is worth noting that the existing natural gas reserves amount to approximately 62.4 trillion cubic feet, out of which 43.6 trillion cubic feet have been confirmed as proven reserves, as reported by the Ministry of Energy and Mineral Resources in 2021. According to estimates, the available reserves of oil and gas are projected to last for a duration of around 9.5 years and 20 years, respectively. This analysis is based on the premise that no novel findings have been made, and the current rate of oil extraction stands at around 0.7 million barrels per day, while gas extraction amounts to 6 billion standard cubic feet per day, as reported by the Ministry of Energy and Mineral Resources in 2021. According to the Ministry of Energy and Mineral Resources (MEMR, 2021), Figure 3 illustrates a fall in oil and gas output attributed to the natural deterioration of reservoir performance and the challenges associated with identifying substantial new reserves. Hence, it is projected that the reserves of oil and gas will exhibit a persistent reduction until the year 2024. According to the projection made by the country, it is anticipated that the quantity of remaining oil reserves in the year 2024 will amount to 1138 million stock tank barrels (MMSTB). This projection indicates a decline of 49% in comparison to the reserves recorded in the year 2020, as illustrated in Figure 4. A similar trend is expected to be observed in the case of natural gas, as it is projected to undergo a decrease of 22% according to the Ministry of Energy and Mineral Resources (MEMR, 2021).

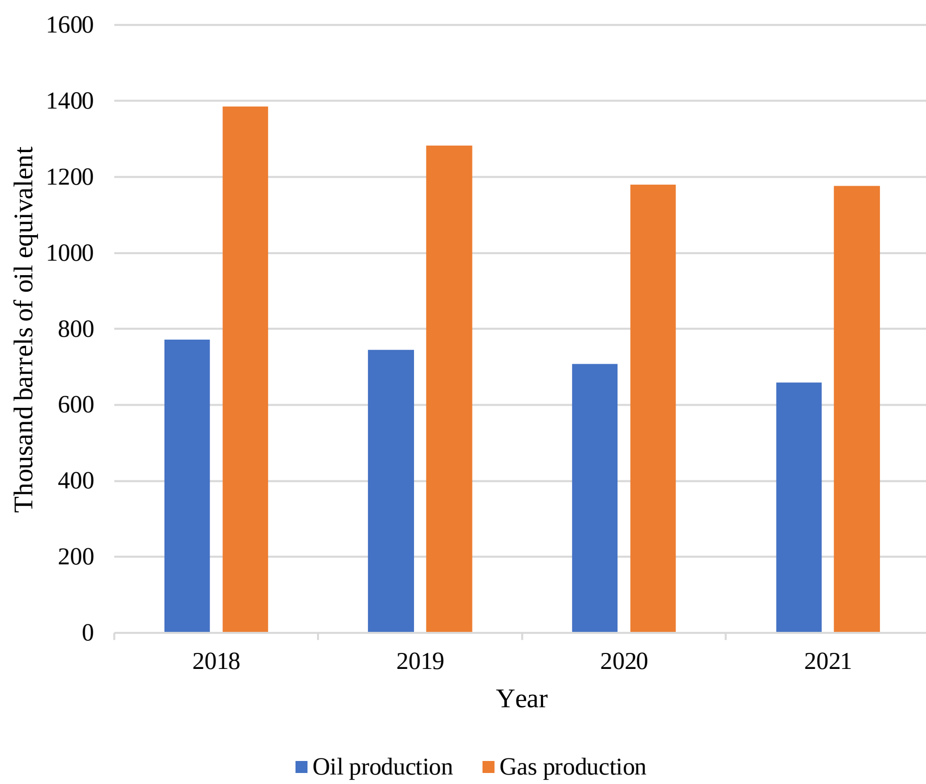

Figure 3. Yearly production of oil and gas in Indonesia (MEMR, 2021).

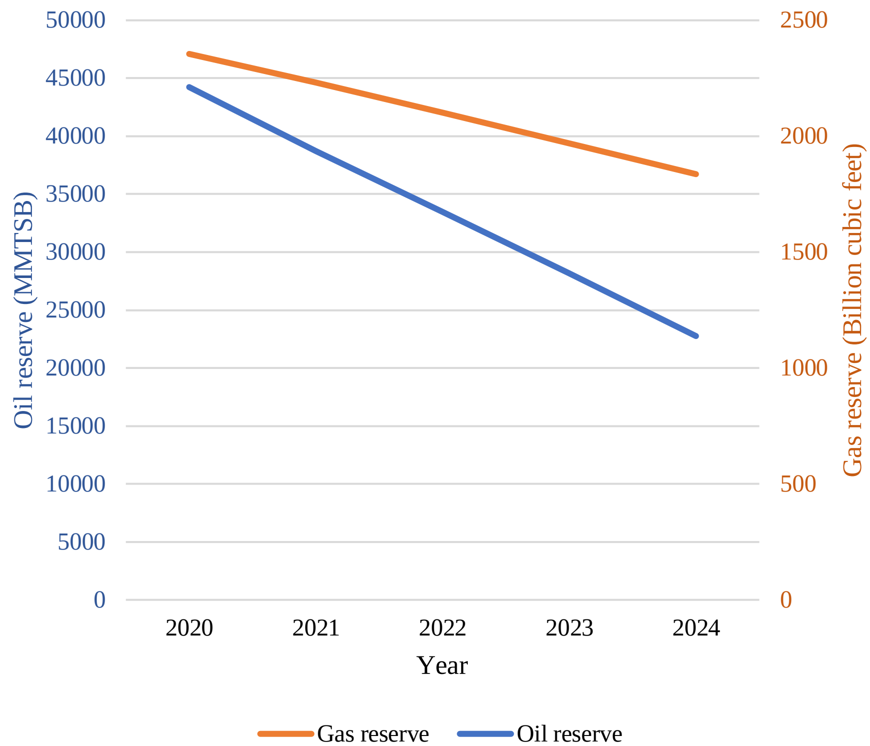

Figure 4. Current and projected reserves of oil and gas in Indonesia (MEMR, 2021).

Coal, like oil and gas, is a non-renewable natural resource that possesses significant strategic worth at both regional and national levels. The Asia Pacific region heavily relies on this particular natural resource to offer cost-effective and accessible sources, particularly during the ongoing pandemic and the Russia-Ukraine conflict (Wicaksana & Ramadhan, 2022). The coal reserves in Indonesia are distributed among 21 provinces, amounting to a total of 39 billion tons. In the year 2021, the average output of coal in Indonesia was recorded at 606 million tons, as reported by the Ministry of Energy and Mineral Resources (MEMR, 2021). There is a 7.2% increase observed in comparison to the previous year, 2020, which recorded a total of 566 million tons, as depicted in Figure 5. Based on current estimates, it is projected that the coal reserves will remain accessible for a period of approximately 65 years, under the assumption that no more deposits are discovered. In addition, it is worth noting that there exists a significant quantity of coal resources, estimated at 144 billion tons. Notably, the majority of these resources, accounting for 62% or 88 billion tons, are concentrated in the region of Kalimantan. Additionally, there are 26 billion tons of coal reserves in this area. Coal deposits are also present in Sumatra, exhibiting a substantial quantity of resources amounting to 55 billion tons, alongside reserves estimated at 13 billion tons (MEMR, 2021).

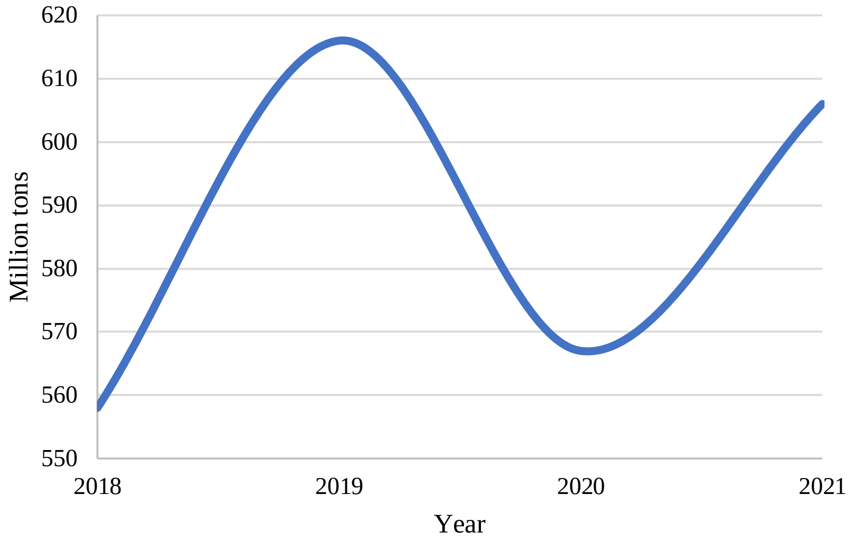

Figure 5. Yearly production of coal in Indonesia (MEMR, 2021).

The utilization of coal can be categorized into two distinct purposes, namely as a primary material and as a source of energy. The utilization of this substance as a primary component encompasses several industrial applications such as the production of coal briquettes, metal processing, coal liquefaction, gasification, and upgrading (Liu et al., 2023). Simultaneously, it finds application in the power production sector, industrial settings, small enterprises, and residential environments as a source of fuel (Chen et al., 2022). Coal has a crucial role in generating state revenue, making it a significant economic resource (Adebayo, 2023). Hence, the management of the aforementioned entity must be conducted in an efficient, transparent, responsible, and equitable manner, so as to provide substantial advantages for the community (Sriwahyuni, 2023). The consideration of environmental changes, both domestically and globally, should be a crucial aspect of government policies aimed at promoting the advancement of coal mining (Triady & Saraswati, 2021).

The demand for renewable energy sources in Indonesia arises from the anticipated decline in the accessibility of non-renewable energy sources (Aswadi et al., 2023). The utilization and viability of renewable energy sources had a significant growth, surging from 5% in 2015 to 11% in 2020. This notable gain may be attributed to the amplified use of biofuels and the integration of renewable energy technologies in the establishment of off-grid power plants, including hydroelectric, geothermal, and solar power facilities (Pandey et al., 2022). Currently, the renewable energy supply in Indonesia amounts to 23 million tons of oil equivalent (TOE), which accounts for around 11% of the total energy supply. This renewable energy mix includes hydro, geothermal, solar, wind, biofuel, and biogas sources. In contrast, the current level of production accounts for a mere 5% of the overall national energy production, as reported by the Ministry of Energy and Mineral Resources in 2021. The production of renewable energy in Indonesia in recent years is depicted in Figure 6. According to the Ministry of Energy and Mineral Resources (MEMR, 2021), there was a rise in the generation capacity of solar power plants from 4.56 Gigawatt hours (GWh) in 2018 to 5.66 GWh in 2021. In the meantime, there has been a notable rise in the consumption of hydropower, with an increase from 10,729 GWh in 2018 to 11,869 GWh in 2021. Comparably, the production of geothermal energy had an upward trend, rising from 4013 GWh in 2018 to 4217 GWh in 2021. The data provided by the Ministry of Energy and Mineral Resources (MEMR, 2021) indicates a growing trend in the adoption of renewable energy sources, leading to a corresponding decline in the utilization of fossil fuels.

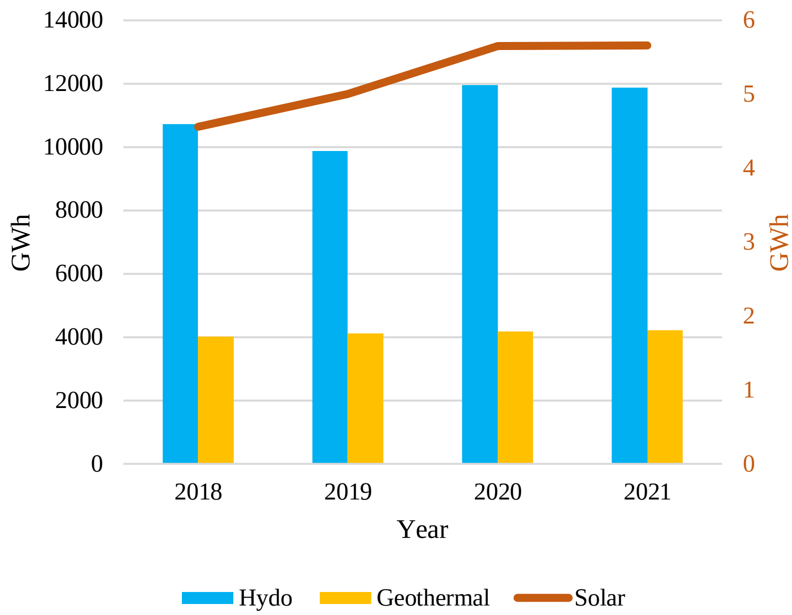

Figure 6. Yearly production of water, geothermal, and solar energy in Indonesia (MEMR, 2021).

Energy Consumption in Indonesia

Energy, being a crucial natural resource, plays a pivotal role in fostering community prosperity (Raihan et al., 2023e; Voumik et al., 2023b; Raihan, 2023j). Consequently, it becomes imperative to implement effective energy management strategies to facilitate sustainable development (Raihan et al., 2022i; Chen et al., 2023; Raihan, 2023k). The Indonesian government has set a goal of achieving a 17% reduction in final energy consumption by the year 2025, along with a 1% decrease in energy intensity. In addition, the Ministry of Energy and Mineral Resources (MEMR, 2021) has set a specific goal of achieving a reduction ranging from 10% to 30% in the industrial, transportation, commercial, and home sectors. In 2021, Indonesia's energy consumption amounted to approximately 939 million barrels of oil equivalent (BOE). The consumption mentioned comprised a biogas oil component, accounting for 46% of the total. This biogas oil component was composed of gasoil, biodiesel, and blended products, with respective proportions of 16%, 7%, and 23% (MEMR, 2021). Additional forms of energy consumption encompass many sources such as oil, electricity, natural gas, coal, liquefied petroleum gas (LPG), biodiesel, biogas, and biomass (MEMR, 2021). The energy consumption of Indonesia in 2021, categorized by energy type, is depicted in Figure 7.

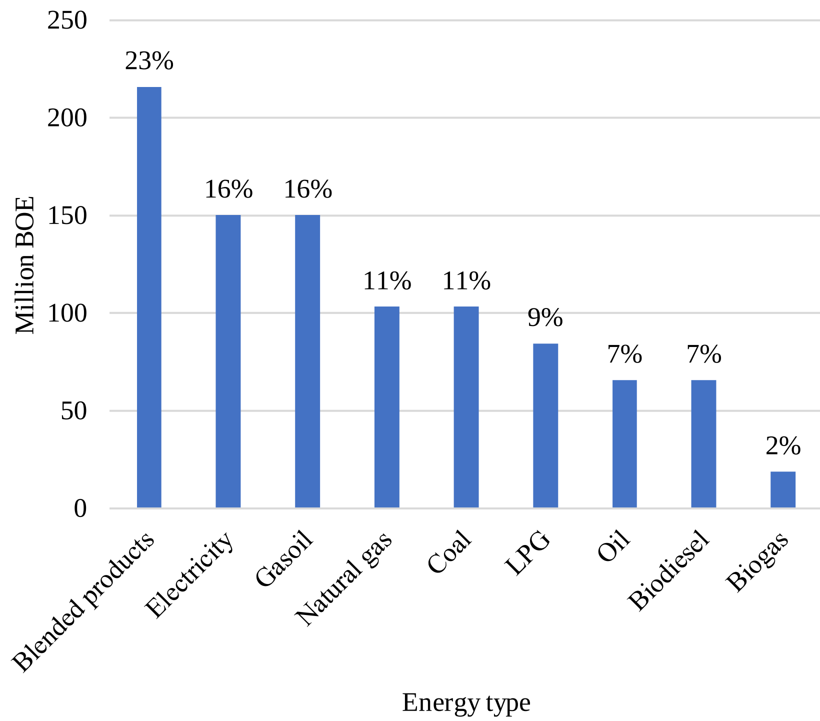

Figure 7. Indonesia's energy consumption in 2021 by energy type (MEMR, 2021).

The energy consumption in Indonesia for the year 2021, categorized by industries, is depicted in Figure 8. According to the Ministry of Energy and Mineral Resources (MEMR, 2021), the transportation sector accounted for the highest proportion of energy consumption, representing nearly 46% of the total energy consumed. The energy consumption rates in industries and families were 31% and 17%, respectively. In addition, it is worth noting that the commercial sector accounts for 5% of total energy consumption, with the remaining energy being allocated to various other sectors (MEMR, 2021). The rise in energy consumption in both the industrial and vehicular sectors can be attributed to the substantial increase in industrial and vehicular operations (Raihan et al., 2023f). The demand in the industrial sector is anticipated to correspond with its growth as outlined in the "Indonesia Vision 2045". In the transportation sector, various factors have had an impact. These include the increasing number of motor vehicles, the implementation of a substitution program aimed at transitioning from conventional to electric cars, the introduction of mandatory biodiesel and bioethanol initiatives, and the transition from private to mass automobiles (NEC, 2019). The projected increase in power consumption is expected to have an impact on the future development of electric vehicles by the year 2035, exhibiting an annual pattern.

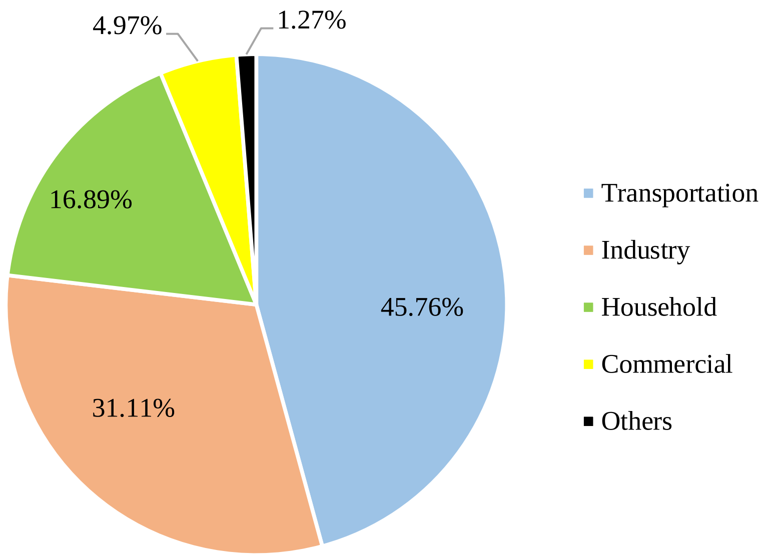

Figure 8. Indonesia's energy consumption in 2021 by sectors (MEMR, 2021).

Fossil fuels are employed as an interim energy resource inside the nation, particularly during the transitional phase before the complete conversion to 100% renewable energy in power generation facilities. Natural gas is employed as a fuel source to supplement intermittent renewable energy facilities, whereas minerals are primarily utilized in the latter stages of production. Nevertheless, the government has initiated a process of diminishing the utilization of coal as an energy source through the implementation of CCS/CCUS (carbon capture, utilization, and storage) technology. Additionally, they are exploring the substitution of LPG with dimethyl ether (DME) and enhancing the value of minerals by means of local downstream activities. According to the Ministry of Energy and Mineral Resources (MEMR, 2022), the emissions from the energy sector in Indonesia for the year 2021 reached a total of 530 million tons of carbon dioxide equivalent (CO_2e). A projection has been made indicating that there will be a rise in peak emissions to around 706 million tons of CO_2e by the year 2039. Nevertheless, it is anticipated that there will be a substantial decrease in emissions post-2040, subsequent to the fulfillment of contracts pertaining to fossil fuel power plants (MEMR, 2022).

The achievement of energy conservation Is presently being pursued through the acceleration of the worldwide energy transition, a process that is bolstered by a collective consensus among all members of the International Energy Agency (IEA) with regard to the promotion of energy efficiency. According to Rabbi et al. (2022), this acceleration has the potential to attain the objective of achieving net-zero emissions on a worldwide scale. The implementation of energy management in Indonesia, particularly in relation to government restrictions on energy conversion, has been designed (Redaputri & Barusman, 2021). The government has also undertaken measures to broaden the scope of the minimum performance standards (MEPS). Furthermore, the aforementioned law includes energy conservation measures, such as the adoption of electric vehicles and induction cookers, which are facilitated through the execution of governmental initiatives. These initiatives encompass the transition from diesel to gas generators, the establishment of rooftop solar power plants, and the conversion of electric motors (MEMR, 2022). According to Yudiartono et al. (2023), the government provides backing for the implementation of induction cookers and the expansion of the gas network, aligning with the objectives outlined in the energy transformation roadmap and the pursuit of carbon neutrality. In addition, it is important to note that the enhancement of energy efficiency in commercial buildings necessitates a comprehensive approach that encompasses both the design phase

and the operational aspects of the structure (Raihan, 2023l). This can be achieved by including efficient equipment and systems, as highlighted by Yudiartono et al. (2022).
In order to facilitate the realization of a zero-emission scenario, a minimum of 47% of a generatio''s energy production must be derived from renewable sources by the year 2030. It is projected that throughout the upcoming decade, the capacity of solar photovoltaic (PV) systems will experience a significant increase, reaching a magnitude of 108 GW, or a hundredfold growth. The primary objective of this initiative is to provide valuable assistance in promoting the adoption of electrification in both the industrial and transportation domains. According to Setiawan et al. (2021), the government has implemented budget tagging as a means of tracking the allocation of public funds towards climate change mitigation and adaptation efforts, specifically in the areas of energy and transportation. Nevertheless, the organization has been unable to effectively mitigate emissions, resulting in consequential implications for budgetary allocations. Over the course of the previous five years, the allocation of the state budget has been primarily directed towards financing the energy and transportation sectors, resulting in a total sum of IDR 221.6 trillion, which accounts for approximately 81.73% of the budget. According to Hilmawan et al. (2021), the existing budget allocations and expenditures are insufficient to meet the National Determined Contributions (NDC) objective of IDR 318.18 trillion years from 2020 to 2030.

Potential Future Development of Renewable Energy

Indonesia, comprising 34 provinces, is characterized as an archipelago abundant in diverse energy resources. Hence, it is imperative to develop a comprehensive cartographic representation that delineates the technical capacity of renewable energy sources (Yana et al., 2022). Additionally, this initiative must facilitate the gradual shift towards the adoption of entirely renewable energy sources, with the ultimate goal of attaining a carbon-neutral Indonesia by the year 2050 (PRRI, 2017). The feasibility of implementing renewable energy solutions is contingent upon the prevailing geographical conditions. In response to this, the government has undertaken the establishment and deployment of power plants across several locations (Putranto et al., 2022). The population and economy have experienced significant exponential growth, which currently exerts a notable influence on climatic patterns, ecological dynamics, and biodiversity. According to Yilanci et al. (2023), there is a tendency for indicators of socioeconomic status and other ecological repercussions to exhibit a correlation with energy demand. In the context of Indonesia, the utilization of fossil fuels, including oil, gas, and coal, remains prevalent. The extensive utilization of this resource contributes to the expansion of the economy, albeit frequently accompanied by environmental degradation that poses the risk of potential catastrophes of natural or human origin (Sharma & Malaviya, 2023).
Regarding the Nationally Determined Contributions (NDCs), all nations throughout the globe, including Indonesia, expressed their dedication to upholding a limit on the increase in global temperature within the range of 1.5 ◦C to 2 ◦C during the initial phase. The objective of this initiative is to achieve a reduction in emissions of 29% by individual efforts, and a more substantial reduction of 41% under the assumption of international collaboration. The forthcoming no-action plan, projected to be executed in 2030, will be accomplished by leveraging various sectors, namely forestry, energy (including transportation), waste management, industrial processes, product utilization, and agriculture. The resolve is reinforced by the legislation enacted by the government to ratify the Paris Agreement under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC). In order to accomplish this objective, Indonesia has established a renewable energy objective within the national energy composition, aiming for a minimum of 23% and 31% by the years 2025 and 2050, respectively. Furthermore, the region exhibits considerable potential for several forms of renewable energy, including solar, hydro, wind, geothermal, and bioenergy or biomass (Raihan et al., 2022h).

Table 1 presents an overview of the efficacy of Indonesi"s renewable energy sources in the year 2021. Despite the considerable renewable energy potential of 420 GW in Indonesia (NEC, 2021), its current use remains limited. Hence, the strategic plan for the development of NZE includes the optimization of renewable energy utilization in power generation, as stated by Utami et al. (2022). The limited adoption of renewable energy sources for power generation can be attributed to the comparatively higher cost of establishing and operating such facilities (Raihan et al., 2022h). This poses a significant challenge in terms of competing with fossil plants, particularly coal. In addition, hindrances to the growth of renewable energy include insufficient domestic industrial backing and challenges in securing low-interest funding (Raihan et al., 2023d).

Table 1. The potency of Indonesia’s renewable energy in 2021 (NEC, 2021).

Type of renewable energy	Potency (GW)
Solar	208
Hydro	75
Wind	61
Bioenergy	32
Geothermal	24
Micro-hydro	19
Total	420

Solar energy

Solar energy is a fast-emerging type of renewable energy that is seeing significant global development (Raihan, 2023m). As a nation situated in a tropical region with consistent solar exposure year-round, there is a pressing need to maximize energy utilization (Sorooshnia et al., 2023). The solar energy potential in Indonesia is substantial, as indicated by a capacity of 208 MW (Junihartomo et al., 2022) and an average sun irradiance of 4.80 kWh/m2/day (Windarta et al., 2019). The assessment of solar potential is an essential initial stage in the adoption of solar energy in Indonesia. Figure 9 illustrates the annual installed capacity of solar power plants in Indonesia. In 2021, the Ministry of Energy and Mineral Resources (MEMR) reported a total installed capacity of 208 MW for the production of solar energy, which is achieved through the generation of both on-grid and off-grid energy (MEMR, 2021).

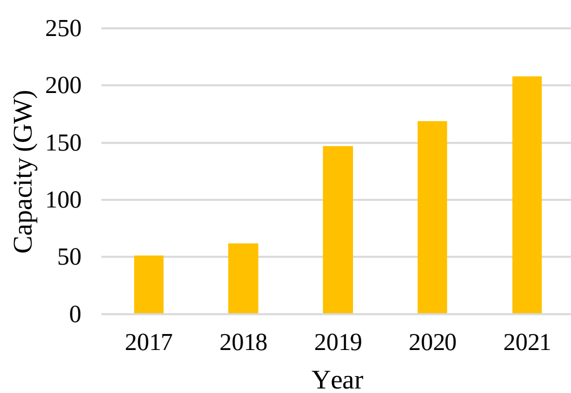

Figure 9. Yearly installed capacity of solar power plant in Indonesia (MEMR, 2021).

The solar power plant exhibits intermittent behavior, characterized by the variability of energy output due to factors such as seasonal circumstances, humidity, temperature, cloud movement, and other weather conditions (Raihan, 2023n). According to Tambunan et al. (2021), the generato''s operational continuity at its installed capacity is compromised. Moreover, the construction process is also associated with significant investment expenses, resulting in an uneconomical selling price of electricity (Tercan et al., 2022). In the year 2019, a regulatory measure was enacted by the government pertaining to the utilization of rooftop solar installations by individual consumers. The primary objective of this law was to facilitate the inclusion of consumers from many sectors, including households, businesses, social government, and industry, in the usage and management of renewable energy. The overarching goal was to enhance energy security and foster self-sufficiency in the energy sector. In addition to the implementation of rooftop solar power plants, it is anticipated that solar energy will also find application in energy-efficient solar lamps (Suparwoko & Qamar, 2022). Moreover, the government has expedited the deployment of energy-efficient solar lighting systems to individuals lacking access to power. The present strategy pertains to the allocation of energy-efficient solar lighting systems in remote, underprivileged, and geographically isolated regions that lack access to conventional power infrastructure (Cahyani et al., 2022; Raihan, 2023o).

The subsequent endeavor entails t''e de'elopment of a solar streetlight, which is an illumination device that harnesses solar energy as its primary source of electrical power. Between the years 2016 and 2020, a total of 65,501 units of solar streetlights were constructed, out of which 18,888 units were successfully installed (NEC, 2021). In 2021, a total of 4829 units were erected during the fourth quarter, specifically targeting road sites that lack connection to the energy network. In the year 2020, the installation of solar plants was categorized into two distinct segments: rooftop installations and installations within cold storage facilities. Furthermore, this technology can be utilized in various architectural structures, serving as both the primary energy source and a supplementary backup system to complement pre-existing power sources (Raihan, 2023p). Cold storage is among the applications of electricity derived from solar power plants. In the year 2021, a total of 100 units were discovered, consisting of 88 units located on rooftops and 12 units stored in public cold storage facilities (NEC, 2021).

In addition to its terrestrial applications, solar power plants can also be deployed in aquatic environments, aligning with the unique geographical characteristics of Indonesia as an archipelagic nation. Silalahi et al. (2021) have identified a significant potential for solar energy in a tropical country. Following this, a floating solar power facility was constructed and deployed in several aquatic environments, including reservoirs, lakes, ponds, and canals (Chirwa et al., 2023). The various elements encompassed under this system consist of solar modules, platforms, pontoons, mooring systems, inverters, power conditions stations, cabling, network interconnection infrastructure, supporting facilities, meteorological centers, remote monitoring, and data gathering systems (Islam et al., 2023). The offshore solar power plant has a greater number of obstacles compared to a conventional land-based solar power plant. These challenges arise from factors such as the limited historical data available, the inherent uncertainty around costs, and the potential environmental impact (Zeng et al., 2023). The design, construction, and operation of this model pose inherent complexities due to its interdependence with electrical, anchoring, and mooring systems (Moodliar & Davidson, 2023).

The utilization of floating solar plants has several notable benefits. Firstly, these installations do not necessitate the use of land, a resource that is typically of high value. Additionally, they contribute to the mitigation of water evaporation and effectively suppress the proliferation of undesirable vegetation, such as water hyacinth (Solomin et al., 2021; Raihan et al., 2022j; Raihan et al., 2023g). In addition, the performance of the PV module is hindered by the implementation of a cooling system, hence enhancing the overall efficiency of power production. At now, it is projected that the construction of the Citara floating plant in Indonesia will be finalized by 2022, followed by the establishment of another plant in the Sutami Reservoir, located in Malang, by 2023. It is projected that the proportion of renewable energy sources in Central Java province will rise to 22% by the year 2025, with a particular emphasis on harnessing solar and geothermal energy resources. The solar potential of this province is estimated to be 4.05 kWh/kWp per day, above the national average of 3.75 kWh/kWp per day. Central Java is home to a total of 42 reservoirs, which possess a significant potential for accommodating floating solar power plants with a combined capacity of 727 MWp. According to a report by the Institute for Essential Services Reform (IESR, 2021), the technical capacity of 11 big reservoirs accounted for 92.3% or 672 MWp of the overall contribution. Additionally, 7.36% (53 MWp) was generated by 24 medium-sized reservoirs, while the remaining 2 MWp was attributed to 7 minor reservoirs.

Hydro energy

Hydroelectric power plants, such as the Jelok Hydro Power Plant, were initially constructed in 1938 during the Dutch era, and are recognized for their dependable energy generation capabilities. The categorization of hydroelectric power generation depending on its scale consists of three classifications: hydro, micro-hydro, and mini-hydro power plants (Hermawati et al., 2023). Figure 10 illustrates the annual installed capacity of hydroelectric power plants in Indonesia. According to the Ministry of Energy and Mineral Resources (MEMR) in 2021, the total potential for hydroelectric power generation was estimated to be 6602 MW. This figure encompasses a hydropower plant with a capacity of 5639 MW, as well as micro-hydro and mini-hydro installations with capacities of 126 MW and 376 MW, respectively.

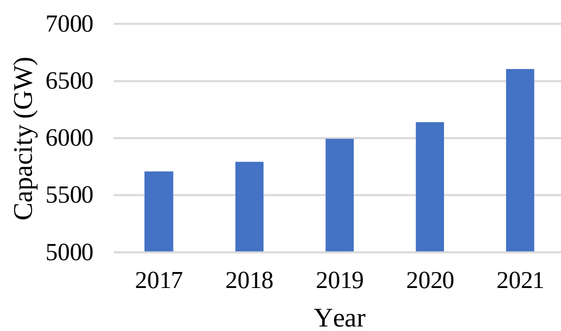

Figure 10. Yearly installed capacity of hydropower plant in Indonesia (MEMR, 2021)

Wind energy

According to PRRI (2017), there is a projected goal for wind power plants to achieve a capacity of 7 GW by the year 2030, with an installed capacity of 2.2 GW. According to Prasita et al. (2022), multiple regions in Indonesia have wind potential characterized by velocities ranging from 4 to 6 m/s. According to PRRI (2017), Indonesia now possesses a wind power facility with an installed capacity of 154.3 MW. However, the country aims to increase its wind power capacity to 255 MW by the year 2025. The nation encompasses two significant botanical entities, specifically Sidrap and Tolo. Sidrap is situated in the Sidenreng Rappang regency and is home to a total of 30 wind turbines, collectively generating a capacity of 75 MW. Tolo is situated in the region of Turatea, which is located in the southern part of Sulawesi. It possesses a total power generation capacity of 72 MW, facilitated by a collection of 20 wind turbines, each having a capacity of 3.6 MW (PRRI, 2017). The potential for wind energy is promising, as there is a prospective opportunity to construct wind power plants in three sub-districts of South Garut, namely

Pameungpeuk, Cibolang, and Cisompet. In 2023, a number of plants are scheduled to be constructed, including the Sukabumi Project and the Tolo II in Jeneponto (PRRI, 2017).

Bioenergy

Aside from bioenergy's application in the power sector, it has the potential to fulfill energy demands in several sectors such as transportation, industry, and households (Rehan et al., 2023). The identification of a wide range of raw materials, including livestock manure, agricultural waste, plantation waste, and urban trash, is readily achievable. The energy derived from various sources such as biomass, biogas, municipal waste, domestic biogas, and bioenergy furnaces has the potential to be utilized as a power source for power plants (Kalak, 2023). Figure 11 illustrates the annual installed capacity of biofuel power plants in Indonesia. According to the Ministry of Energy and Mineral Resources (MEMR, 2021), the total installed capacity of bioenergy power plants in the year 2021 amounted to 2284 MW. The national energy strategy aims to achieve a capacity of 9.6 GW generated from bioenergy power plants, as well as 1.09 GW generated from biomass, biogas, and waste bioenergy sources. The ample potential of bioenergy presents expanded prospects for the younger demographic to actively contribute to endeavors aimed at advancing bioenergy and clean energy across diverse sectors (MEMR, 2020). Within the realm of academia, it is imperative to go further into the exploration of research and innovation development opportunities in order to fully harness the potential of domestic bioenergy. Community service activities coordinated by universities have the potential to make valuable contributions toward the advancement of bioenergy utilization in everyday community settings.

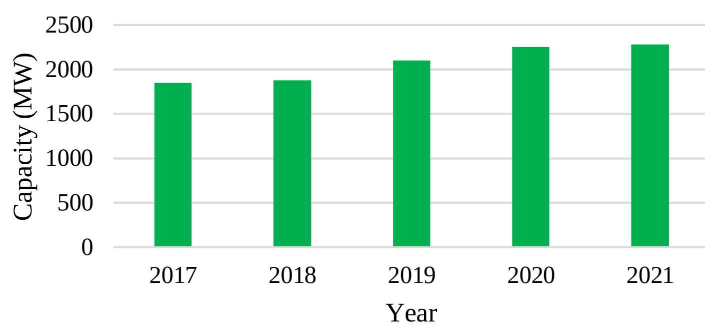

Figure 11. Yearly installed capacity of bioenergy power plant in Indonesia (MEMR, 2021).

Biomass refers to organic matter derived from living organisms, encompassing both flora and fauna, as well as their associated byproducts (Yana et al., 2022). In the Indonesian context, several industrial waste materials, including but not limited to palm oil, tapioca, pulp and paper, sugar cane, rice, and wood, have the potential for extraction. According to the Ministry of Energy and Mineral Resources (MEMR, 2021), the estimated biomass potential for generating energy in 2021 is 32,654 MW. Out of this total, there is an installed capacity of 152 MW for on-grid systems and 1970 MW for off-grid systems. The potential for biomass energy in the future lies in its ability to be effectively harnessed through the co-firing technique, which involves blending biomass with coal within a steam power plant. The co-firing process involves the utilization of garbage and wood as primary raw materials (Szufa et al., 2023). In addition, it is worth noting that the country has a potential capacity of 2603 MW for biogas production. According to the Ministry of Energy and Mineral Resources (MEMR, 2021), the power generation capacity of on-grid and off-grid biogas plants in 2021 was reported to be 22 MW and 113 MW, respectively. Furthermore, biogas possesses the potential to serve as a source of energy not just for power plants but also for residential households through the utilization of cow dung and household trash, a practice commonly referred to as communal biogas development (Nadan & Baroutian, 2023).

Biofuels typically consist of energy and constituents derived from plants and biomass (Gnanasekaran et al., 2023). The body of literature pertaining to the production of biofuels derived from biomass resources through ecologically sustainable approaches has been steadily growing (Khan et al., 2022). A range of liquid and gaseous biofuels can be derived from biomass, including ethanol, biodiesel, methane, methanol, and bio-oil (Kazmi et al., 2023). In order to promote the utilization of renewable energy sources, researchers have undertaken endeavors to blend palm oil with diesel oil as a means of generating biodiesel (Gunawan et al., 2023). In addition, there have been endeavors to blend ethanol derived from the processing of sugarcane with gasoline in order to generate bioethanol. In 2021, the implementation of biofuel use has achieved a volume of 6.66 million kiloliters, which represents a proportion of the initial target of 10.2 million kiloliters designated for domestic consumption. The potential of biofuel as a viable alternative to petroleum has garnered significant attention, leading to the exploration of many sources including terrestrial and marine plants, such as microalgae, for the production of alternative energy (Singh et al., 2023).

In addition, it is worth noting that the trash generated by the community has the potential to serve as an energy resource capable of generating an estimated 2000 MW of power (MEMR, 2020). The waste-to-energy facility situated in Benowo, Surabaya presently possesses a power generation capacity of 12 MW. Its operations commenced on the 6th of May 2021. The outlook appears promising since there are multiple locations encompassing Jakarta, Surabaya, Tangerang, Semarang, Bandung, Surakarta, Denpasar, Makassar, Manado, Bekasi, Palembang, and South Tangerang City. The proposed development plan entails the allocation of 38 MW, 29 MW, 10 MW, and 9 MW of power generation capacity in Jakarta, Bandung, Surakarta, and Bekasi City, respectively. According to the National Energy Council (NEC, 2021), the five remaining cities, namely Makassar, Palembang, Manado, South Tangerang, and Denpasar, possess an equivalent capacity of 20 MW apiece.

Geothermal energy

The development of geothermal energy commenced a century ago, marked by the inaugural drilling of a geothermal well at Kamojang by the Dutch in 1926. This geothermal facility has been in operation since 1983, as documented by Fajarudin et al. (2022). According to the Ministry of Energy and Mineral Resources (MEMR, 2021), Indonesia possesses a geothermal capacity of 23,766 MW. The specific allocation of this capacity is outlined in Table 2. Nevertheless, as depicted in Figure 12, the installed capacity in the year 2021 amounted to 2286 MW, indicating a significant amount of untapped potential in geothermal energy utilization. Hence, the government aims to achieve a rise in geothermal use to 7242 MW, equivalent to 16.8%, by the year 2025 (PRRI, 2017).

Table 2. Geothermal energy potential in 2021 by region (MEMR, 2021).

Region	Potency (MW)
Sumatra	9,517
Java	8,050
Sulawesi	3,071
Nusa Tenggara	1,399
Maluku	1,144
Bali	335
Kalimantan	175
Papua	75
Total	23,766

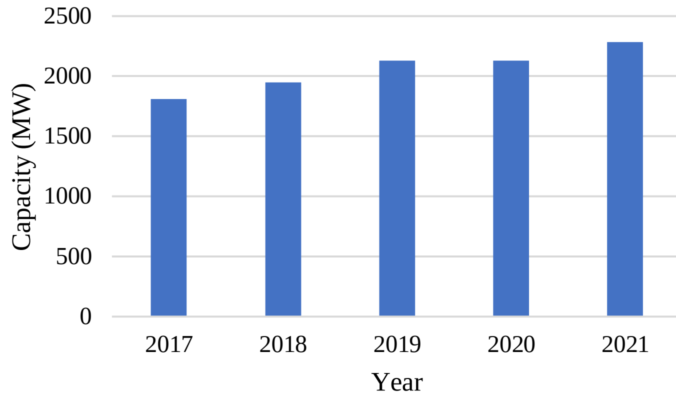

Figure 12. Yearly installed capacity of geothermal power plant in Indonesia (MEMR, 2021).

Nuclear energy

Uranium and thorium, both radioactive components, are among the fundamental raw resources utilized in nuclear manufacturing (Putri et al., 2022). According to the National Energy Council (NEC, 2021), Indonesia possesses a combined quantity of 81,091 tons of uranium resources and 140,411 tons of thorium reserves. Table 3 presents the estimated potential of uranium and thorium resources within the geographical boundaries of Indonesia. According to Wisnubroto et al. (2023), Indonesia possesses the capacity to establish nuclear power facilities in order to meet its domestic energy requirements, with support from the commercial and industrial sectors. Southeast Asia has the potential to become the first region in the area to establish a nuclear power plant, mostly driven by the presence of uranium resources. This development holds the promise of transforming uranium into a significant export commodity (Km, 2022). In relation to its influence, this form of energy has the capacity to mitigate the generated waste without exerting any discernible influence on power expenses. According to Krūmiņš and Kļaviņš (2023), the environmentally friendly outcome is disposed of in the ground to prevent any adverse impacts on the local community.

Table 3. Indonesia's prospective uranium and thorium reserves (NEC, 2021).

Region	Uranium (ton)	Thorium (ton)
Sumatra	31,567	126,821
Kalimantan	45,731	7,028
Sulawesi	3,793	6,562
Total	81,091	140,411

Conclusion

Renewable energy is suitable for powering social and economic infrastructure. The characteristics are sustainability, affordability, reliability, and improved safety. The Indonesian government is promoting renewable energy. Thus, this study suggests using solar, hydro, wind, bioenergy, and geothermal energy sources to harvest significant amounts of energy. Indonesia has also implemented energy policies and intends to increase its renewable energy mix. The country wants to increase renewable energy from 11% in 2021 to 23% in 2025 and 31% by 2050. This research also provides energy landscape information. In 2021, coal energy produced 559 million barrels of oil equivalent (BOE), while renewable energy produced 181 million. Energy supply, production, and consumption are interdependent, creating balance. The current situation may determine sustainable energy implementation steps. Indonesia's primary energy sources, excluding biomass, grew 3.5% year from 2015 to 2020 while preserving energy balance. Energy production in 2020 was 443 million tons of oil equivalent (TOE), with roughly 95% coming from fossil fuels like oil, gas, and coal. The 2021 trend of energy consumption per type is up 1%, or 939 million barrels of oil equivalent. Energy consumption is highest in the transportation sector, at 46%. This sector uses gasoline as its main fuel. According to energy consumption figures, fossil fuel use is still high and rising. Thus, Indonesia's vast renewable energy resources must be maximized.

The NZE power plant development strategy optimizes renewable energy sources for electricity generation. Renewable energy and energy conversion sub-sector performance targets are set for 2022. These aims include a 15.7% primary energy mix and 366 MBOE production. Many renewable power plants help the government reduce steam power plant coal use. The solar energy resource has a theoretical capacity of 207,898 MW with an average irradiation of 4.80 kWh/m2/day. Hydro energy sources have 95 GW of potential, including 75,000 MW of hydro and 19,370 MW of micro-hydro. The present wind energy capacity in Indonesia is 154 MW, with a goal of 255 MW by 2025. Bioenergy is used in biomass, biogas, municipal garbage, households, and power plants. The total bioenergy capacity is 32,653.8 MW. Geothermal power stations can generate 23,965 gigawatts. The switch from fossil fuels to renewable energy could boost the nation's economy. However, private sector investments in renewable energy projects are needed to lower transition costs. This review paper will help guide Indonesia in developing and implementing renewable energy policies.

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Authors Contribution: Asif Raihan contributed to conceptualization, visualization, methodology, reviewing literature, extracting information, synthesize, and manuscript writing.

Data availability: The author confirms that the data supporting the findings of this study are available within the article.

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