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MORALITY BEFORE KNOWLEDGE

Combination of non-renewable and renewable natural resources for sustainable energy provision in Indonesia

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ABSTRACT

Background: Development, as part of the process of advancing civilization, requires energy as one of its fundamental resources. This paper discusses the planning of a scenario for the utilization mix of non-renewable and renewable natural resources for sustainable energy supply in Indonesia. **Methods:** The quantitative method is used to determine the amount of energy imports that need to be reduced by utilizing renewable energy, the amount of renewable energy potential that can be optimized, and recommendations for a more ambitious but realistic energy mix. The qualitative method is used to identify which recommendations are currently effective, which are not, and those that have not yet been proposed to improve an energy mix that meets sustainability aspects. **Findings:** The results of a system dynamics model review support the need to accelerate the optimization of renewable energy utilization to achieve energy resilience and a strategy for developing low-carbon emission energy. To optimize the use of renewable energy, fiscal incentives from the government are necessary, along with the restructuring of energy prices to make renewable energy more competitive, support for renewable energy technology development, PLN's (State Electricity Company/*Perusahaan Listrik Negara*) commitment to using renewable energy with government incentives, and consistent implementation of renewable energy regulations. **Conclusion:** The energy mix strategy during this transition period is to continue increasing oil production through exploration and Enhanced Oil Recovery (EOR), optimize gas and coal with clean technology, and aggressively utilize renewable energy to reduce the oil import gap while transitioning to renewable energy to achieve a sustainable energy future. **Novelty/Originality of this article:** This article lies in its integrative use of system dynamics modeling and a mixed-method approach to propose a comprehensive, ambitious-yet-realistic energy mix strategy for Indonesia that balances non-renewable and renewable resources to achieve energy sustainability and reduce dependency on imports.

KEYWORDS: energy mix strategy; energy resilience in Indonesia; low-carbon development; renewable energy optimization; sustainable energy supply.

1. Introduction

Indonesia, as a developing country, requires natural resources as a capital for development, including both non-renewable energy sources (oil, gas, and coal) and renewable energy sources (geothermal, solar, wind, water, biomass, etc.) (Partowidagdo, 2009). Non-renewable natural resources, or often referred to in literature as "stock," are natural resources that cannot be produced on a scale comparable to their rate of consumption. This means that these resources are finite (exhaustible) and cannot be replenished. Activities such as coal, oil, and natural gas mining are forms of exploitation of non-renewable natural resources.

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Currently, the energy mix in Indonesia is dominated by fossil energy resources, accounting for 91% (coal, oil, and gas), while only 9% comes from renewable energy sources (National Energy Council, 2019). Oil and natural gas, as non-renewable resources, are expected to experience declining production, as shown in the oil and gas production curve in Indonesia in Figure 1. Similarly, coal production will also decrease over time.

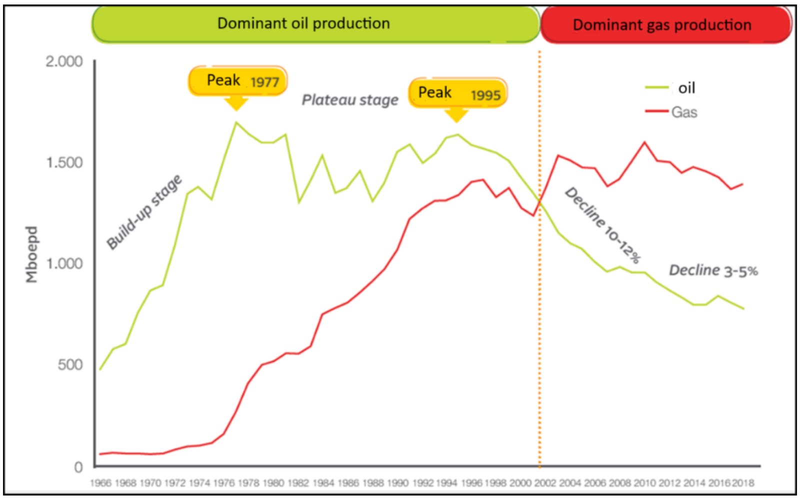

Fig. 1 Oil and gas production in Indonesia
(SKKMIGAS, 2018)

Indonesia is a country that currently relies on the utilization of fossil fuel resources as the dominant energy source, which is non-renewable. This energy is the foundation of economic development, modern life, and energy. Continuous use of fossil energy can lead to serious threats such as the depletion of oil reserves, price instability due to higher demand, and greenhouse gas emissions, which damage the environment and atmosphere due to fossil fuel combustion. The Global Carbon Project (2019) estimates that in Indonesia, carbon dioxide emissions will reach 615 million tons ($MtCO_2$) in 2018 (Figure 2). This number represents an increase of 4.7% from 2016 and 5.13% from 2017. Simultaneously, Indonesia contributes to 36.573 million tons of global carbon dioxide emissions, with 1.7% coming from Indonesia. These emissions are produced from cement production, oil combustion, and land-use changes (Adisaputro & Saputra, 2017).

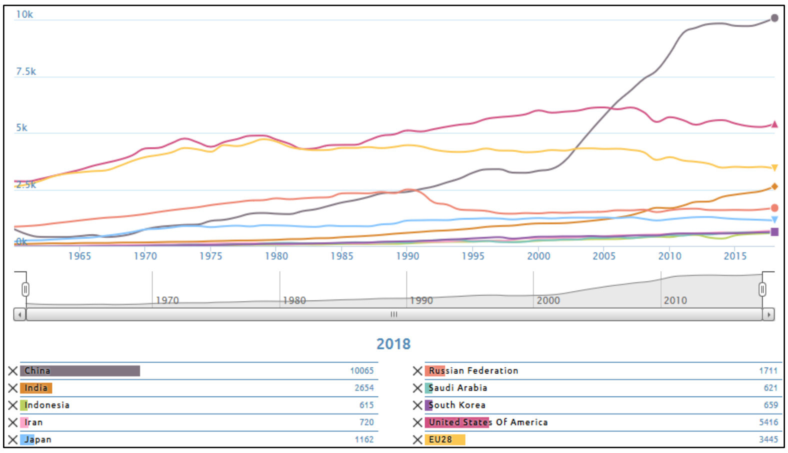

Fig. 2. CO_2 emissions from 1960-2018
(Global Carbon Project, 2019)

To reduce the use of fossil energy and implement clean or environmentally friendly energy, renewable energy has become a key focus of the Indonesian government (Jaelani, 2017). Indonesia has significant potential for renewable energy, some of which include biodiesel as a substitute for diesel, solar power plants, wind, micro-hydro, and biogas generated from animal waste to produce electricity (Firdaus et al., 2019). However, increasing the use of renewable energy and promoting low-carbon development is still constrained by economic viability, policies, and regulations.

2. Methods

The data used in this research are secondary data. The secondary data utilized are related to understanding the factors influencing energy demand and supply conditions, the externalities associated with fossil energy, the potential optimization of renewable energy in the national energy mix as an effort toward transitioning to sustainable energy, and other supporting data related to the analysis of sustainable energy scenario planning.

The research conducted uses a quantitative approach, and the research methods employed include both qualitative and quantitative methods. The quantitative methods to be carried out are as follows: First, statistical data analysis from secondary data on development indicators, energy potential and production, and carbon emissions, as detailed in the data section. Second, quantitative data will provide information on the amount of energy imports that need to be reduced through the utilization of renewable energy, the potential of renewable energy that can be further optimized, and recommendations for a more ambitious yet realistic energy mix. The qualitative methods to be implemented are as follows, First, a review of energy policies in Indonesia based on the National Energy Plan/*Kebijakan Energi Nasional* (KEN) and the National Energy General Plan (RUEN). Second, a review of system dynamics results and their recommendations. Third, based on qualitative analysis, recommendations will be made regarding which policies are currently effective, which are not effective, and recommendations that have not yet been made to improve the energy mix that meets sustainability aspects.

3. Results and Discussion

3.1 Demographics, development indicators, and energy demand in Indonesia

3.1.1 Population projection data in Indonesia

According to data from BPS (2018), the population of Indonesia from 2015 to 2025 is projected to remain relatively stable. In 2015, Indonesia's population was 255.6 million, according to both Scenario A and Scenario B. Scenario A assumes policy implementation, while Scenario B serves as a benchmark assuming trends continue. In 2025, Indonesia's population is projected to reach 282.4 million in Scenario A and 282.0 million in Scenario B. Over this ten-year period, the growth rate is 1.00% in Scenario A and 0.99% in Scenario B.

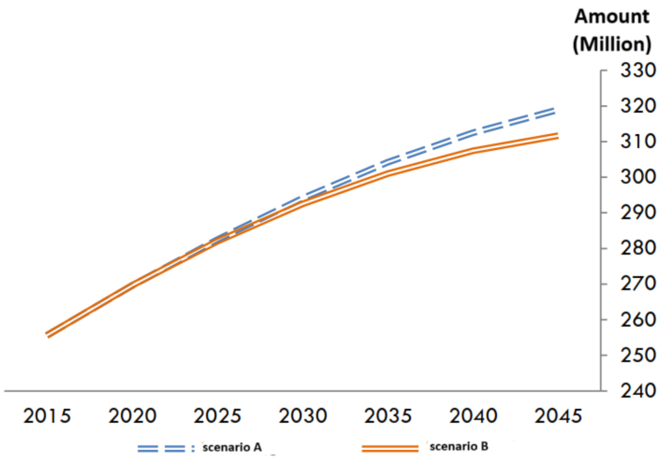

Fig. 3. Population projection of Indonesia from 2015-2045
(BPS, 2018)

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From the calculations using Scenario A, the population of Indonesia in 2030 is projected to be 294.1 million, while in 2045 it is expected to reach 318.9 million. Under Scenario B, Indonesia's population in 2030 is projected at 292.5 million, and in 2045, it is projected to be 311.6 million. The population growth rate in Scenario B is 0.42%, which is slower compared to the 0.54% growth rate in Scenario A. These projections indicate that the population growth in Indonesia from 2015 to 2045 is expected to be 0.74% in Scenario A and 0.66% in Scenario B.

The age composition of Indonesia's population is expected to change due to an increase in the elderly population. The elderly population refers to those aged 60 years and older. The increase in this age group implies a decline in birth rates and an improvement in life expectancy year by year. Scenario A shows that the percentage of the elderly will rise from 9% in 2015 to 19.8% in 2045, while Scenario B projects an increase from 9% in 2015 to 19.7% in 2045.

3.1.2 GDP data, and per capita income in Indonesia

The general income of the Indonesian population is reflected by the national income per capita. This income is influenced by two factors: Gross Domestic Product (GDP) or Gross National Product (GNP). Both GDP and national income have increased, both in current prices and constant prices, since 2014.

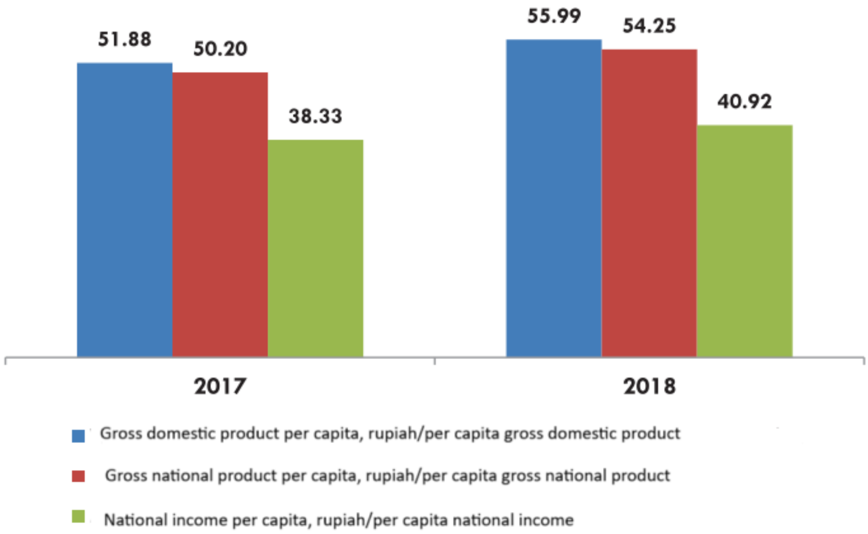


Fig. 4. GDP, GNP, and national income per capita at current prices for 2017 and 2018**
(BPS, 2019)

Figure 4 shows that GDP per capita at current prices increased by 7.91% from 2017 to 2018, from IDR 51,881,199.6 in 2017 to IDR 55,986,859.2 in 2018. GNP per capita increased by 8.08% during the same period, from IDR 50,196,103.9 in 2017 to IDR 54,251,126.8 in 2018. Similarly, national income per capita grew by 6.76%, from IDR 38,325,249.8 in 2017 to IDR 40,916,368.2 in 2018.

3.1.3 Energy demand data in Indonesia

According to data from the Ministry of Energy and Mineral Resources (Ministry of Energy and Mineral Resources, 2018a, 2018b), as shown in Figure 5, the highest energy consumption from 2007 to 2017 occurred in 2012, with a total of 817 million barrels of oil equivalent (SBM). Overall, energy consumption continued to rise until 2017. By sector, the highest energy consumption occurred in the transportation and industrial sectors, while the commercial sector consumed the least.

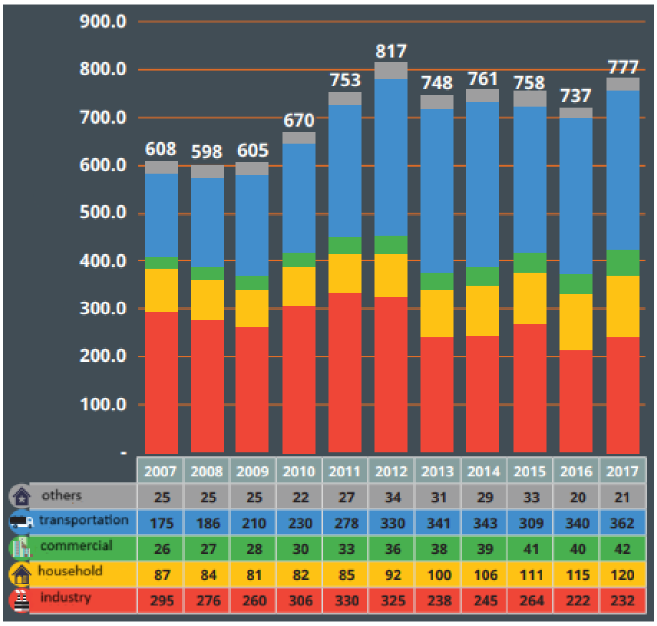


Fig. 5. Energy consumption in Indonesia by sector
(Ministry of ESDM, 2018)

3.2 Projection of fossil energy production and reserves in Indonesia

3.2.1 Fossil energy reserves in Indonesia

As of 2018, Indonesia's total oil reserves were recorded at 7.51 billion barrels, with 42% being proven reserves and 58% being potential reserves (Ministry of ESDM, 2018). The proven reserves in 2018 decreased compared to the previous decade, while potential reserves increased (Figure 6).

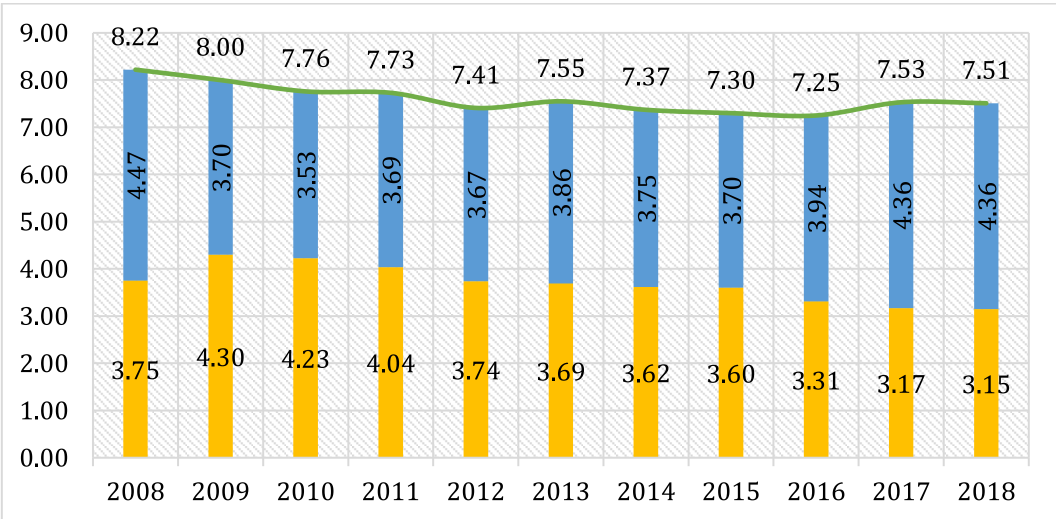


Fig. 6. Oil reserves in Indonesia
(Ministry of ESDM, 2018)

3.2.2. Natural gas reserves

Indonesia's natural gas reserves have decreased, both in terms of proven and potential reserves. According to the Ministry of ESDM (2018), the total gas reserves as of 2018 amounted to 135.55 Trillion Standard Cubic Feet (TSCF) (Figure 7).

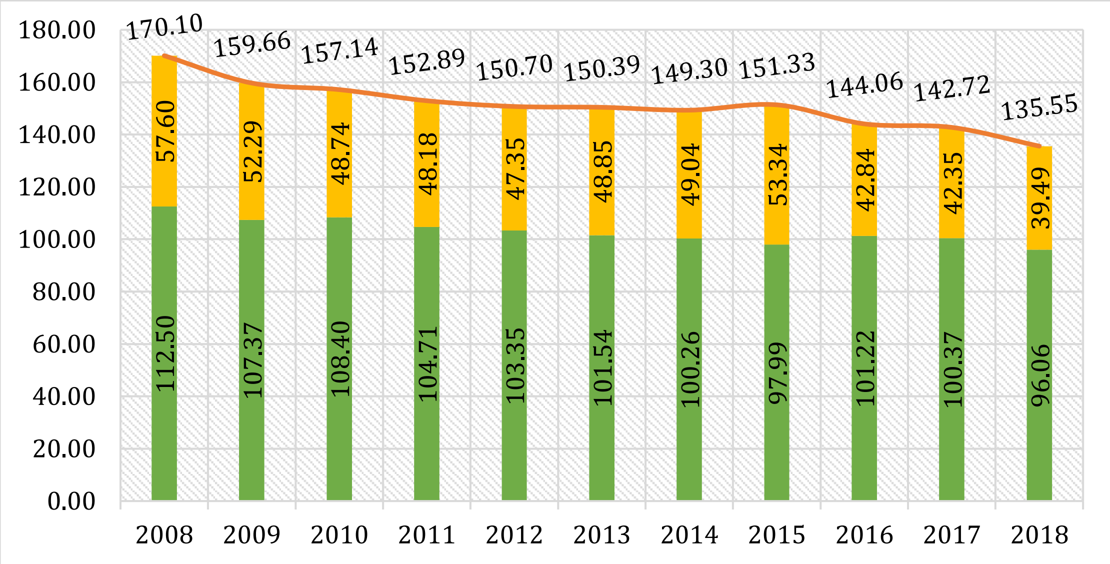


Fig. 7. Natural gas reserves in Indonesia
(Ministry of ESDM, 2018)

3.2.3. Coal reserves

Indonesia holds the fifth-largest coal reserves in the world and remains a primary source of energy, particularly for power plants and some industrial sectors. As of 2018, Indonesia's coal reserves amounted to 39,891 million tons, with measured resources having the potential to increase to 50,764 million tons. The coal production in 2018 was 557 million tons (Ministry of ESDM, 2018). Based on the reserve-to-production ratio, it is projected that Indonesia's coal reserves will last for approximately 70 years, assuming no new reserves are found and production does not decrease due to the use of alternative energy (Figure 8).

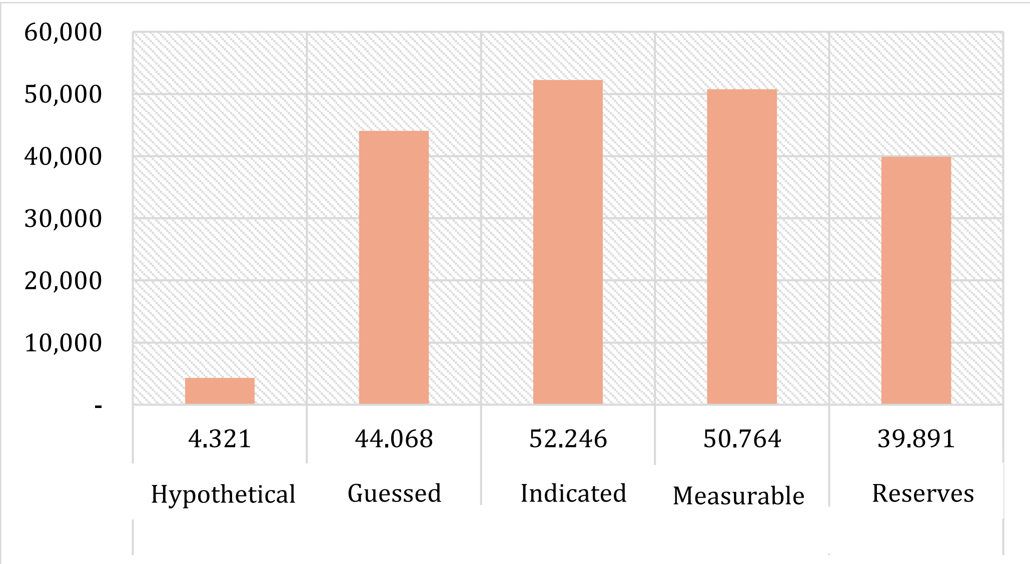


Fig. 8. Coal resources and reserves in Indonesia
(Ministry of ESDM, 2018)

3.3 Projection of fossil energy production in Indonesia

3.3.1 Oil production

Indonesia's oil production from 2020 to 2050 is expected to decline as oil reserves decrease. This is due to limited oil and gas exploration and a low exploration success rate.

Additionally, the decline in oil production is influenced by an unfavorable investment climate for the oil and gas sector and the underutilization of Enhanced Oil Recovery (EOR) technologies. To meet domestic demand until 2050, an estimated 146.6 Million Tons of Oil Equivalent (MTOE) will be needed Business-as-Usual (BaU). This value is three times higher than the oil supply in 2018, which was only 106.4 MTOE. The projection of oil supply can be seen in Figure 9.

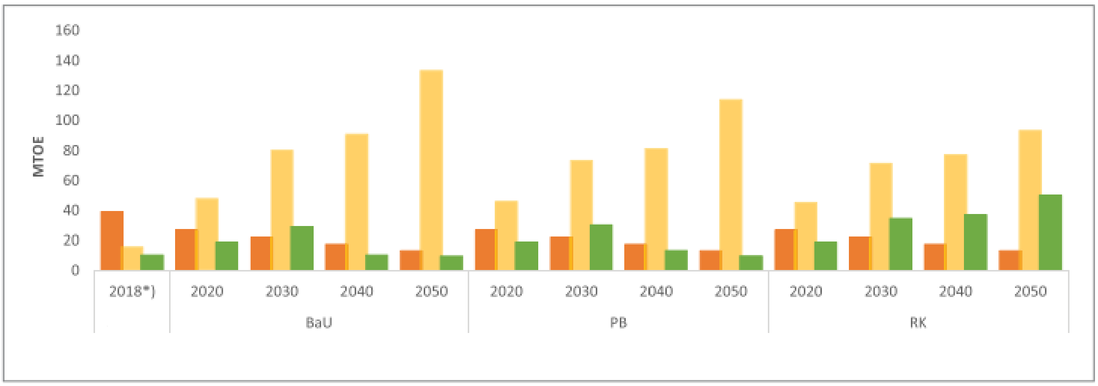


Fig. 9. Oil production projection in Indonesia
(Ministry of ESDM, 2018)

3.3.2. Natural gas production

The natural gas supply is projected to reach 167.4 MTOE by 2050 under the MTOE scenario, which is three times higher than the gas supply in 2018. Meanwhile, under the PB scenario, the gas supply is expected to be 154.2 MTOE, and under the RK scenario, it is projected at 140.3 MTOE. Similar to oil, gas production will decrease due to the lack of new gas reserves. The decline is projected to be from 75.4 MTOE in 2018 to 66.3 MTOE by 2050 for all three scenarios.

Fig. 10. Natural gas production projection in Indonesia
(Ministry of ESDM, 2018)

The government aims to stop gas exports once the current export contracts expire in order to maximize domestic gas usage (Aresiganto, 2009). As a result, Indonesia is expected to cease being a gas exporter by 2040. However, the industrial sector and power plants will continue to require gas, so imports are expected to begin in 2020. Gas imports are projected to be 101.1 MTOE (BaU), 87.8 MTOE (PB), and 74 MTOE (RK) by 2050. Additionally, LPG imports are expected to rise from 6.8 MTOE in 2018 to 14.9 MTOE (BaU), 13.4 MTOE (PB), and 11.4 MTOE (RK) in 2050. The variations in these projections depend on assumptions related to the substitution of LPG with induction cookers and the replacement of LPG with

Dimethyl Ether (DME). A complete overview of gas supply projections over the forecast period.

3.3.3. Coal production

Domestic production is expected to meet coal supply, while high-calorific coal for industrial use will be sourced from imports (Figure 11). The government has set a production cap of 400 million tons per year as per the National Energy General Plan (RUEN) to maintain reserves and prioritize domestic coal use. As a result, coal exports will gradually decrease. In 2018, Indonesia's coal production was 557 million tons, with 64% of the production going for exports and 36% meeting domestic needs. Overall, Indonesia's coal production has increased year on year due to higher export demand, and the proportion of coal used domestically has grown relative to exports (Figure 10).

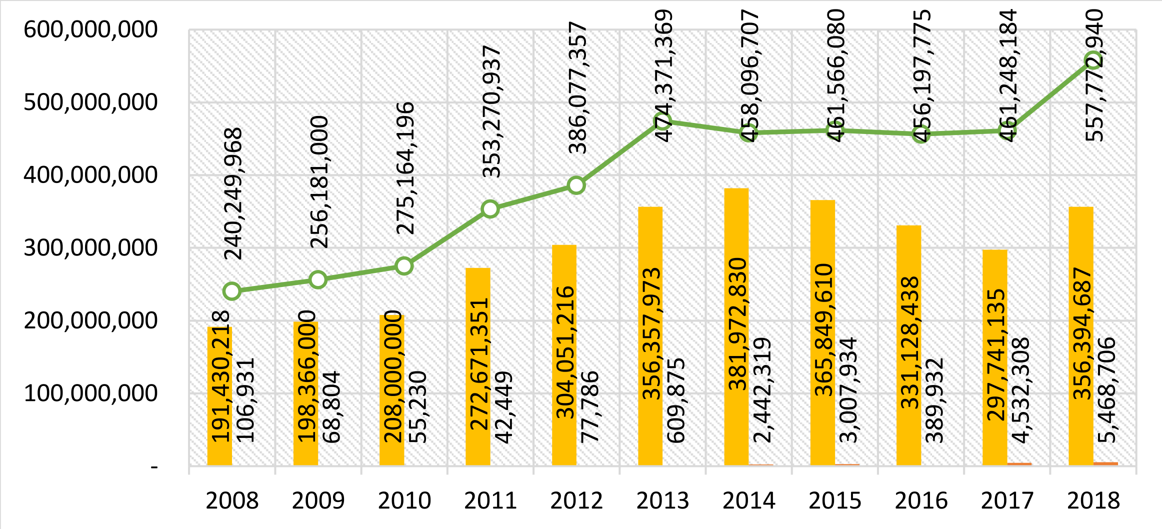


Fig. 11. Coal production in Indonesia
(Ministry of ESDM, 2018)

By 2050, coal exports are projected to decline to 44 MTOE (BaU), 55.8 MTOE (PB), and 67.6 MTOE (RK), compared to 170.3 MTOE in 2018. The share of exports as a percentage of total production will decrease from 64% in 2018 to 18% (BaU), 23% (PB), and 28% (RK) by 2050. The coal supply projection can be seen in Figure 12.

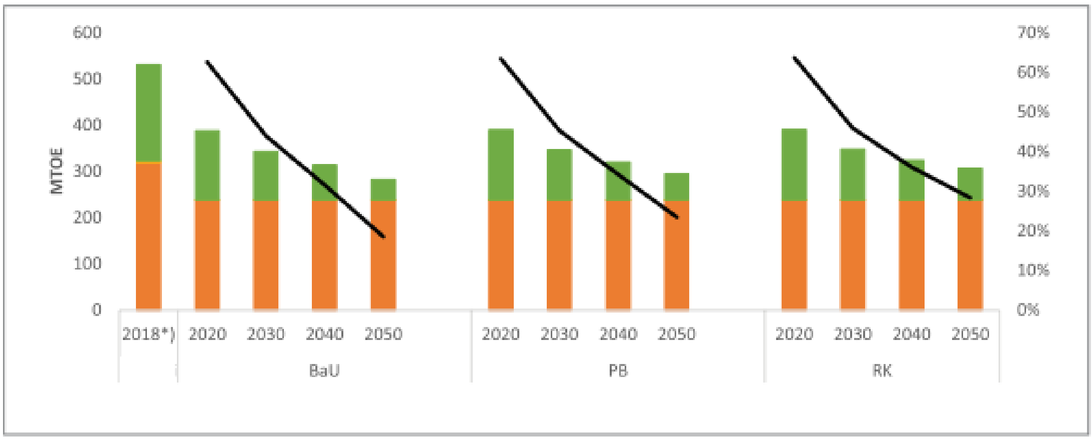


Fig. 12. Coal supply projection
(Ministry of ESDM, 2018)

3.4 Potential and projection of renewable energy

As oil production declines and Indonesia continues its commitment to reducing greenhouse gas emissions, there is growing awareness of the need to consistently increase the share of new and renewable energy (EBT) in order to maintain energy security and independence. The target for the energy mix of new and renewable energy, according to Government Regulation No. 79 of 2014 on the National Energy Policy, is at least 23% by 2025 and at least 31% by 2050. Indonesia has significant renewable energy potential, including hydropower, geothermal, bioenergy, solar, wind, and marine energy. The renewable energy potential in Indonesia is presented in Table 1.

Table 1. Renewable energy potential in Indonesia

Types of energy	Potential
Hydropower	94.6 GW
Geothermal	28.5 GW
Bioenergy	PLT Bio: 32.6 GW and BBN: 200,000 Bph
Solar	207.8 GWp
Wind	60.0 GW
Ocean energy	17.9 GW

(Ministry of ESDM, 2019)

According to the Ministry of ESDM (2019), the total renewable energy potential is equivalent to 442 GW for electricity generation, while biofuels (BBN) and biogas amount to 200 thousand barrels per day (Bph), which can be used for fuel in the transportation, household, commercial, and industrial sectors (Yudha, 2019). In 2018, the utilization of renewable energy for electricity generation reached 8.8 GW, or 14% of the total electricity generation capacity (both fossil and non-fossil), which was 64.5 GW.

3.5 Energy supply and demand curve in Indonesia

As oil production declines and Indonesia continues its commitment to reducing greenhouse gas emissions, there is growing awareness of the need to consistently increase the share of new and renewable energy (EBT) in order to maintain energy security and independence. The target for the energy mix of new and renewable energy, according to Government Regulation No. 79 of 2014 on the National Energy Policy, is at least 23% by 2025 and at least 31% by 2050. Indonesia has significant renewable energy potential, including hydropower, geothermal, bioenergy, solar, wind, and marine energy. The renewable energy potential in Indonesia is presented in Table 1.

3.5.1 Crude oil

Indonesia's crude oil supply in 2018 was 557,722 barrels per day (bbl), a decline compared to the previous years. The majority of the oil was used to meet import needs, with the remainder allocated for export.

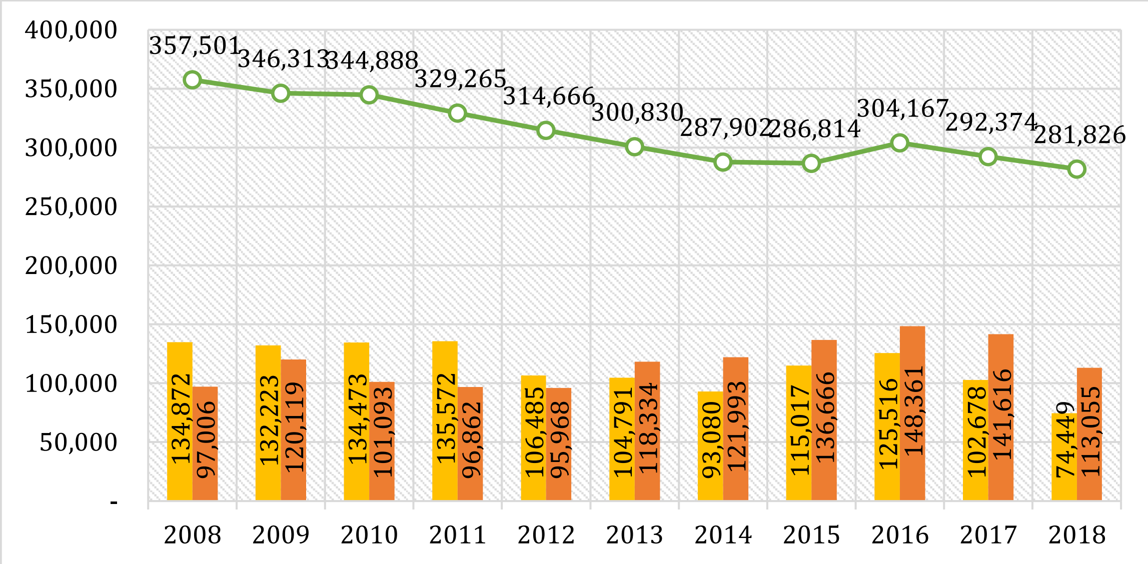


Fig. 13. Crude oil supply and demand
(Ministry of ESDM, 2018)

3.5.2 Natural gas

Generally, natural gas production peaked in 2010 and has been declining since then, with production levels continuing to decrease through 2018. Meanwhile, the demand for gas exports has remained relatively stable during this period (Figure 14).

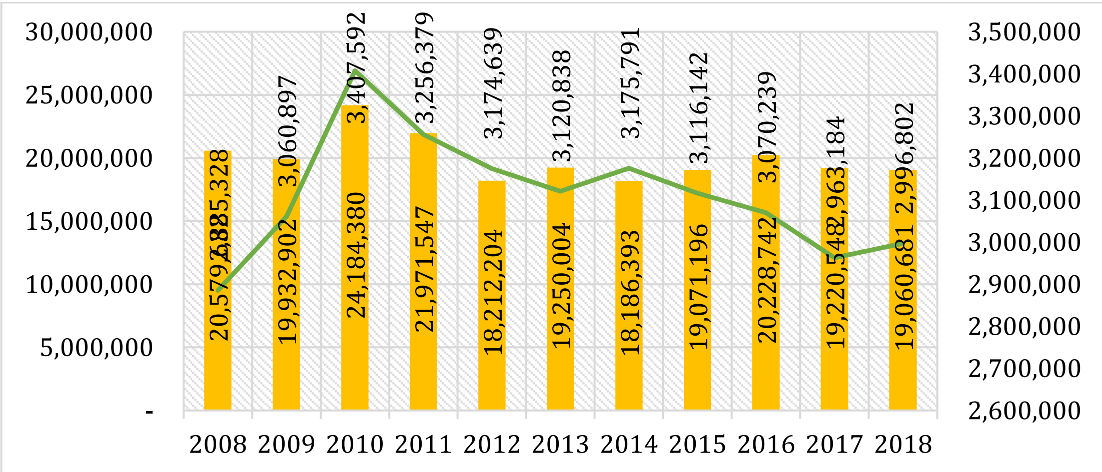


Fig. 14. Natural gas supply and demand
(Ministry of ESDM, 2018)

3.6 System dynamics of energy security in Indonesia

To analyze the challenges in managing the energy mix in Indonesia, Sani et al. (2018) created a system dynamics model of Indonesia's energy mix to depict the behavior of energy supply and consumption in the country, represented through a Causal Loop Diagram (CLD) shown in Figure 15. The CLD consists of the following components: (1) reinforcing Loop A: Government policies → Fossil-dominated economic system → Electricity demand; (2) Balancing Loop B: Government policies → Supply-demand gap → Fossil energy dependency; (3) Balancing Loop C: Energy poverty circle (supply-demand gap for oil, gas, coal, and biomass → Renewable energy). Subsequently, the Causal Feedback Diagram (CFD) is translated into a Stock-Flow Diagram (SFD), which illustrates the relationship between policies and the management portfolio of energy mix in Indonesia, as shown in Figure 14. The SFD model depicts the population, power plants using domestic oil, gas, coal, biomass, imported oil, as well as power plants using biofuels, hydro, geothermal, conceptual solar, and conceptual nuclear energy.

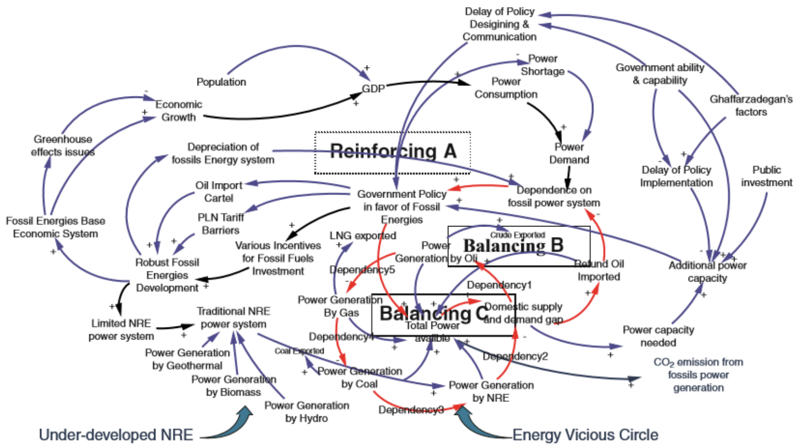


Fig. 15. CLD – system dynamics model of Indonesia's energy mix
(Sani et al., 2018)

The system model shows that the oil sector is the main priority for meeting national energy demand, despite its limitations in national production, environmental impact (carbon emissions), and price volatility. The gas sector ranks second due to its more environmentally friendly nature, stable supply, long-term pricing, and new reserve discoveries. Coal, with abundant reserves and ease of exploitation, holds a larger share in the electricity supply system and could replace oil shortages, though its technology is not environmentally friendly. The last sector is new and renewable energy (NRE), which is still considered a last resort in energy supply portfolio management. Despite abundant reserves and environmental friendliness, this sector lags in exploration, exploitation, and utilization. This is influenced by the long-held premise that renewable energy technology is more expensive, as long-term external costs of fossil fuels are not factored in. This has led to delays in the development of renewable energy sources.

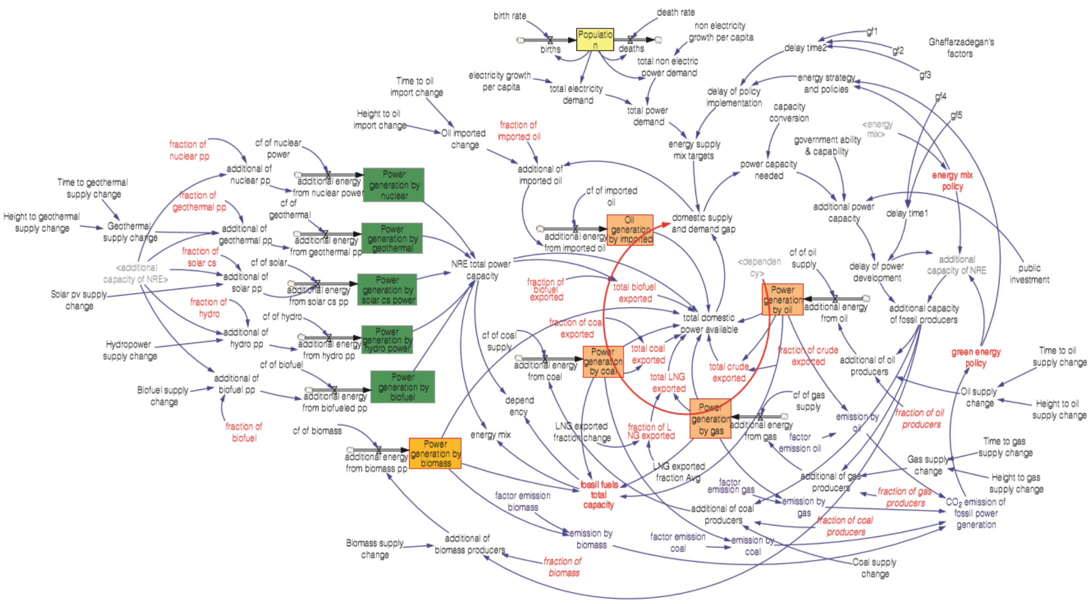


Fig. 16. SFD – system dynamics model of Indonesia's energy mix
(Sani et al., 2018)

The energy mix scenario in Indonesia is illustrated in Table 2, which includes energy mix policies, green energy policies, import portions, government capacity and capability, renewable energy investment, and scenario delays to anticipate risks in policy implementation.

Table 2. Indonesia's energy mix scenarios

Scenario	Energy mix policy	Green energy policy	Fraction of oil imported	Government ability & capacity	Public investment on NRE	Delay time 1	Delay time 2
Scenario old 1	(energy mix <0.25, 0.12, 0.12)	(CO_2 emission >50, 0, 0)	35%	40%	10%	2	2
Scenario old 2	(energy mis <0.75, 0.3, 0.3)	(CO_2 emission >10, 0, 0)	15%	40%	60%	0.5	0.5

(Sani et al., 2018)

The outcomes of the System Dynamics simulation for the energy supply mix profile in Indonesia for both scenarios are shown in Figure 17.

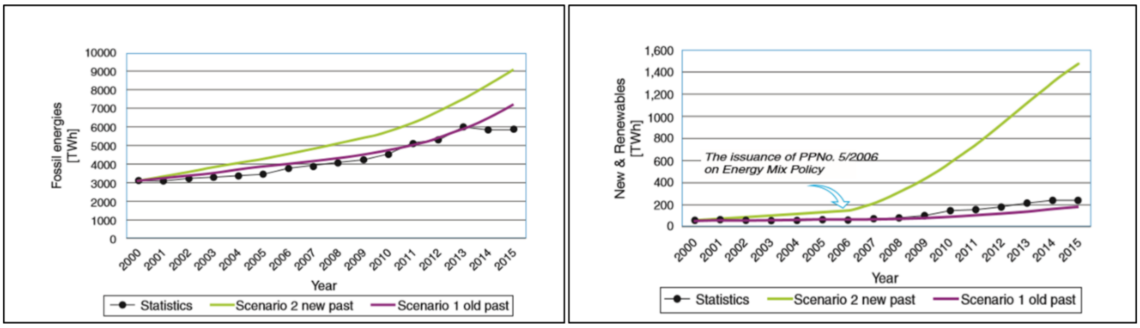


Fig. 17. System dynamics profile of Indonesia's energy mix for fossil and renewable energy
(Sani et al., 2018)

Further outcomes for the production profiles of oil, gas, coal, biofuel, biomass, geothermal, and hydropower are shown in Figures 18, 19, 20, and 21.

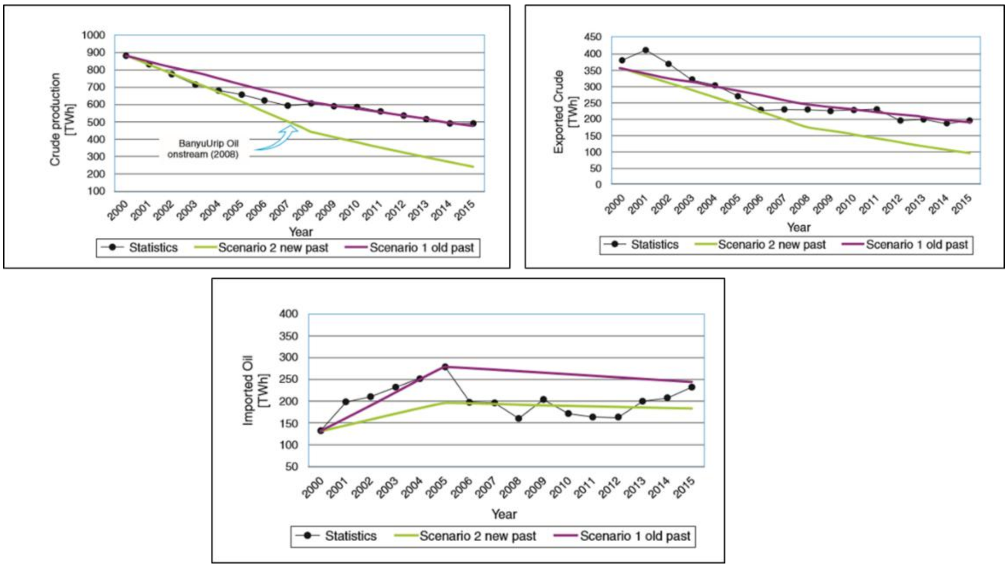


Fig. 18. System dynamics profile of oil production, exports, and imports in Indonesia
(Sani et al., 2018)

The three graphs in Table 18, illustrate trends in Indonesia's crude oil production, crude oil exports, and oil imports from 2000 to 2015 under two projected scenarios ("Scenario 1 old past" and "Scenario 2 new past") compared to actual statistical data. Crude oil production shows a consistent decline across all datasets, with a slight increase in 2008 due to the Banyuurip Oil onstream, yet overall continuing to drop. Crude oil exports similarly decline over time, with Scenario 2 projecting a steeper decrease than Scenario 1. Conversely, oil imports display an upward trend, particularly in Scenario 1, indicating growing dependency on foreign oil. The statistical data fluctuates more than the projected scenarios, but aligns more closely with Scenario 1, highlighting the nation's increasing reliance on imported oil as domestic production and exports diminish.

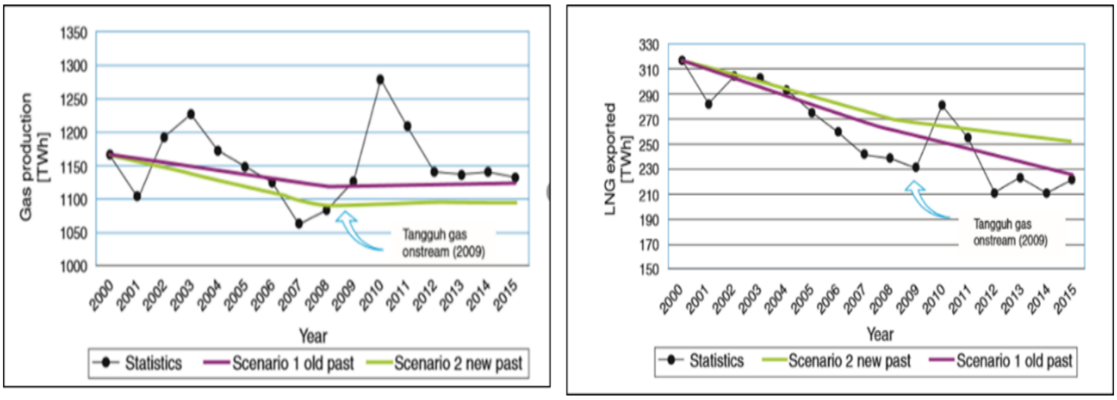


Fig. 19. System dynamics profile of gas production and LNG exports in Indonesia (Sani et al., 2018)

The graphs in Table 19 present trends in Indonesia’s gas production and LNG exports from 2000 to 2015, comparing actual statistics with two projection scenarios: Scenario 1 (old past) and Scenario 2 (new past). Gas production shows fluctuating actual data, particularly peaking in 2010, with a slight boost following the Tangguh gas project becoming operational in 2009. Both scenarios project relatively stable or slightly declining trends, with Scenario 1 closely aligning with the statistical average. In contrast, LNG exports exhibit a steady decline across all data sets, despite the addition of the Tangguh gas facility. The actual export statistics drop more sharply than both scenarios, reflecting a decreasing share of gas being allocated for export, likely due to rising domestic demand.

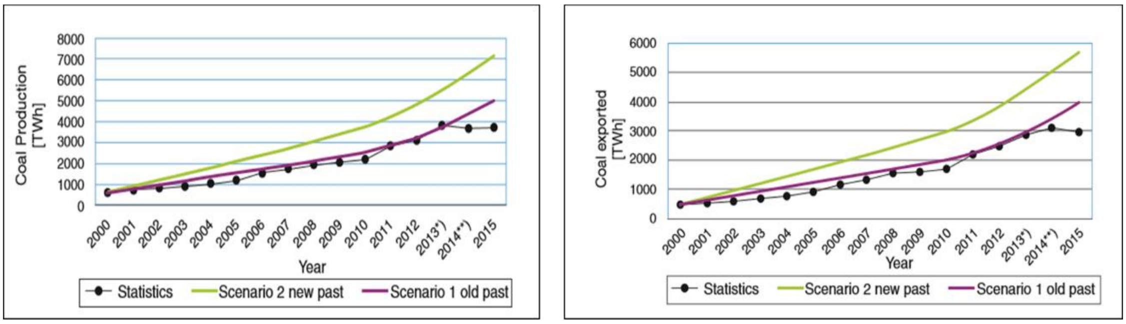


Fig. 20. System dynamics profile of coal production and exports in Indonesia (Sani et al., 2018)

The graphs (Table 20), illustrate the trends in Indonesia’s coal production and coal exports from 2000 to 2015, comparing actual statistical data with two projection scenarios. Both coal production and export volumes show a consistent upward trajectory across all datasets, with Scenario 2 (new past) projecting the highest growth, particularly after 2010. Scenario 1 (old past) follows a more moderate increase, aligning more closely with the actual statistics, especially between 2000 and 2010. Despite being lower than both projections, the actual data also reflects significant growth, indicating the rapid expansion of Indonesia’s coal industry and its increasing role in international energy markets.

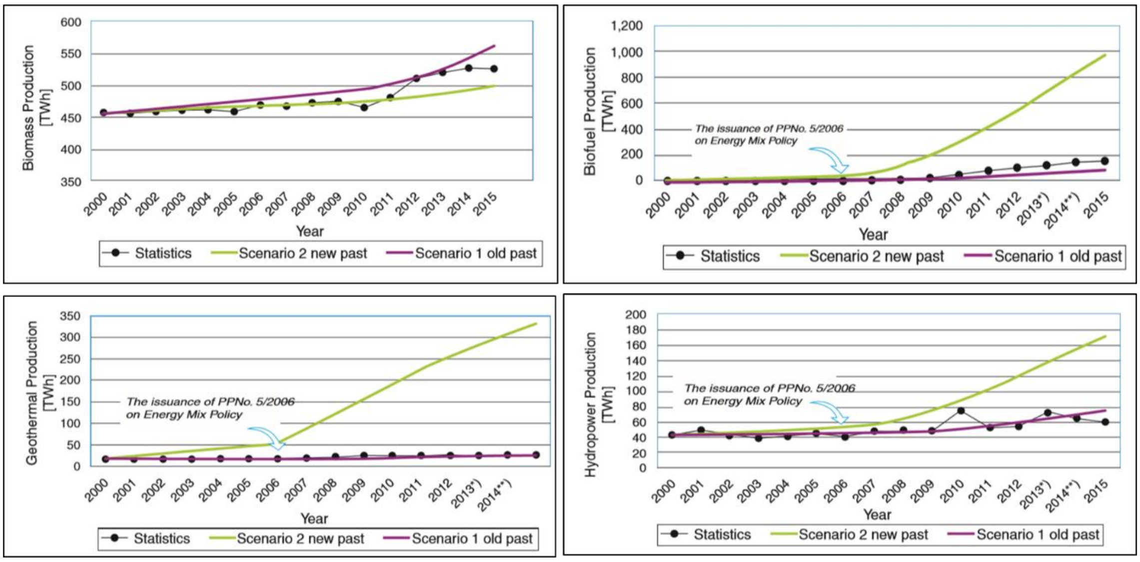


Fig. 21. System dynamics profile of biomass, biofuel, geothermal, and hydropower production in Indonesia
(Sani et al., 2018)

Meanwhile, Sadli (2014) developed a system dynamics model for low-carbon energy security. The CLD in Figures xy and yz shows CLDs for a Business as Usual (BAU) scenario (using fossil oil energy) and two intervention scenarios: the combination of oil and natural gas, and the combination of oil, natural gas, and geothermal energy.

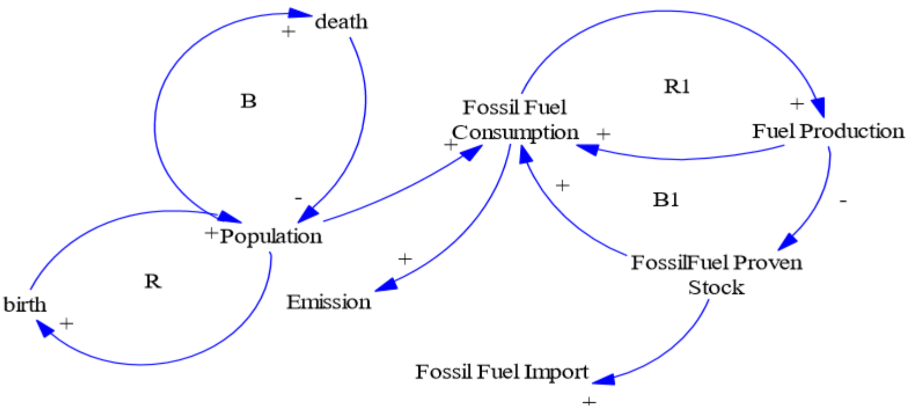
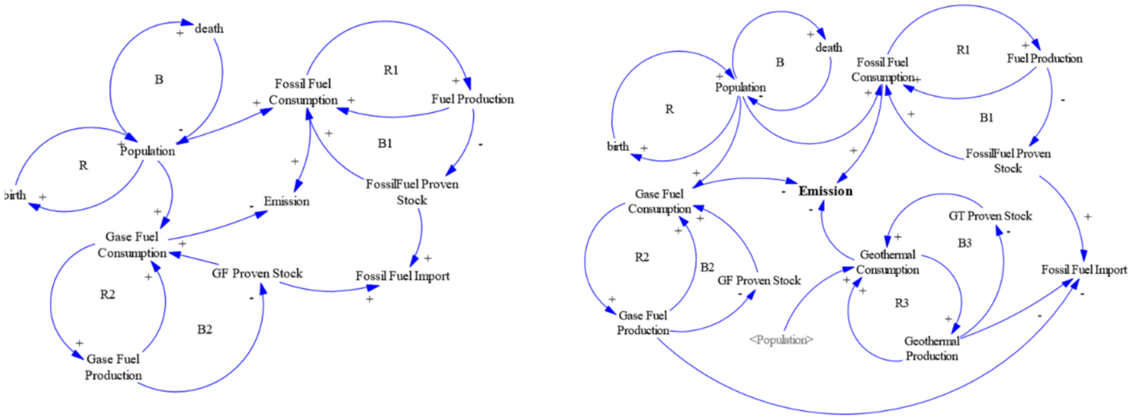


Fig. 22. BAU scenario – fossil oil energy
(Sadli, 2014)

The causal loop diagram illustrates the complex interplay between population growth, fossil fuel consumption, and energy resource dynamics within a system characterized by reinforcing and balancing feedback loops. As the population increases due to a higher birth rate, the total population further fuels more births, forming a reinforcing loop that accelerates demographic expansion. However, this growth is moderated by a balancing loop through the death rate, which rises in tandem with population, thereby stabilizing long-term growth. The expanding population inevitably drives up fossil fuel consumption, leading to higher emissions and prompting increased domestic fuel production to meet rising energy demands. This dynamic creates another reinforcing loop, where greater production supports continued consumption. Yet, the system also includes a crucial balancing mechanism: as fuel is extracted and used, the proven stock of fossil fuels declines, which in turn limits future production capacity. To offset this depletion, the system relies increasingly on fossil fuel imports, ensuring the continuity of supply and sustaining the growing consumption. Together, these interlinked feedback loops reveal how demographic pressures and finite energy resources interact, influencing policy decisions around sustainable energy production and resource management.



CLD Skenario Intervensi 1 – BBG (Gas Fuel)

CLD Skenario Intervensi 2 – BBG (Gas Fuel) dan Panas bumi (geothermal)

Fig. 23. Intervention scenario 1 (oil and gas) and intervention scenario 2 (oil, gas, and geothermal) (Sadli, 2014)

From the system dynamics simulation results, carbon emissions predictions for the BAU, Intervention 1, and Intervention 2 scenarios are shown in Figure 24. Scenario 2, which adds a portion of geothermal and natural gas, shows lower carbon emissions compared to BAU and Intervention 1.

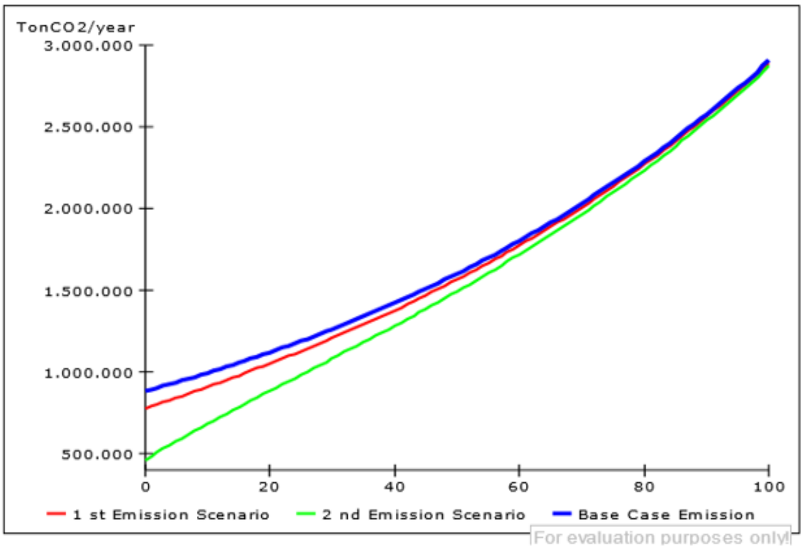


Fig. 24. Carbon emissions predictions using system dynamics for BAU, intervention 1, and intervention 2 scenarios
(Sadli, 2014)

Sustainability analysis uses the approach from the World Energy Trilemma Index, published by the World Energy Council (WEC) and Oliver Wyman, which assesses components of energy security, environmental sustainability, and energy equity as shown in Figure xy.

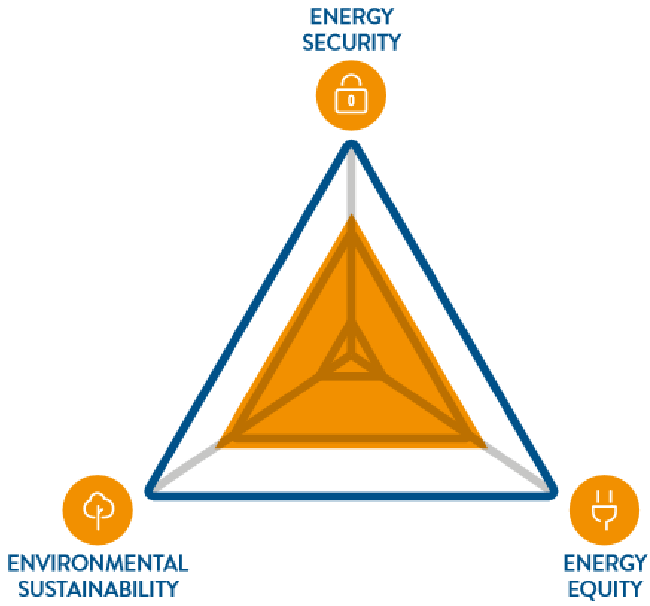


Fig. 25. Energy sustainability index according to WEC
(WEC, 2019)

According to the WEC 2019 report, Figures 26 and 27 show Indonesia's energy sustainability assessment.

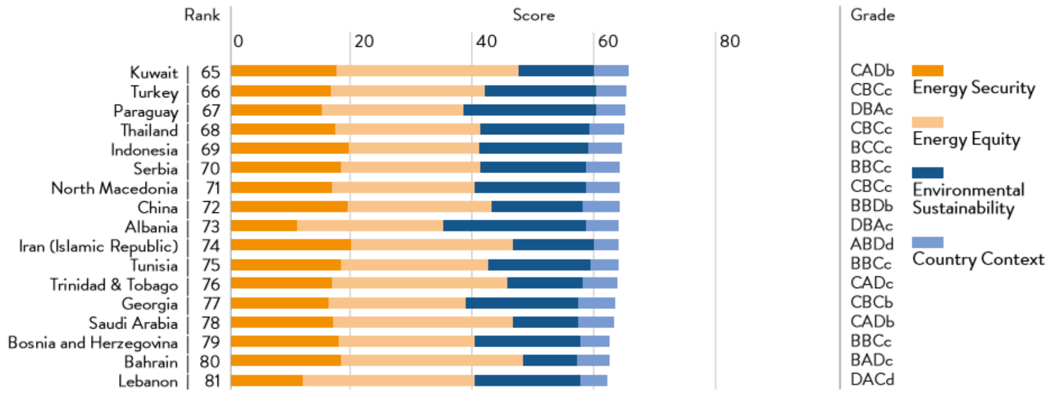


Fig. 26. Energy sustainability index of Indonesia according to WEC
(WEC, 2019)

The bar chart presents the performance of 17 countries ranked from 65 to 81 in terms of their energy trilemma scores, which evaluate energy security, energy equity, and environmental sustainability (Prambudi & Nakano, 2012). Each country is represented by a combination of colored bars indicating their respective scores across the three dimensions, with the overall score shown on a scale from 0 to 80. Countries like Kuwait, Turkey, and Paraguay rank higher (65–67) due to relatively stronger performance in energy security and equity, although environmental sustainability remains modest. On the other hand, countries such as Lebanon, Bahrain, and Bosnia and Herzegovina (ranks 79–81) tend to perform poorly across most metrics, especially in energy security. The accompanying grades provide a letter-based assessment of each dimension, reflecting that while some nations may excel in one area (e.g., Iran in energy equity), they may lag significantly in others, particularly sustainability. The visualization underscores the ongoing challenge for countries to achieve a balanced and sustainable energy system across all three pillars.

Fig. 27. Energy sustainability index of Indonesia according to WEC
(WEC, 2019)

3.7 Energy policy issues in Indonesia

Energy pricing policy in Indonesia is not determined through market mechanisms, but rather is set administratively by the government (INOVASI, 2005). There are four key factors that must be considered in determining energy prices. First, the objective of economic efficiency: to meet domestic energy needs at the lowest possible price while maintaining oil reserves for export purposes, particularly by encouraging the domestic market to substitute its consumption with alternative fuels that are more abundant, such as gas and coal, or non-renewable energy sources like hydropower and geothermal. Second, the objective of mobilizing funds: by maximizing export revenues and government budget revenues from the export of tradable energy resources like oil and gas, and coal, while allowing producers of these energy sources to cover their economic costs and obtain funds to finance growth and development (Yoesgiantoro, 2000). Third, the social objective (equity): to encourage equitable distribution through expanding access to basic needs that rely on energy, such as lighting, cooking, and public transportation. Fourth, the environmental sustainability objective: to minimize environmental pollution resulting from the burning of energy sources.

The four objectives above are factors that need to be taken into account when determining energy policy so that potential conflicts between objectives can be addressed. However, these four objectives are unlikely to be fully achieved because conflicts between them are inevitable.

3.8 Current and future energy conditions in Indonesia

Based on the type of energy (Figure 28), Indonesia dominated energy consumption until 2015, reaching 380.08 million SBM, with a share of 36.79%. This was followed by biomass at 29.95%, electricity at 12.03%, gas at 9.17%, coal at 6.80%, and LPG at 5.26%. However, projections show a shift in trends by 2030. The projected results indicate that Indonesia will still dominate the types of energy consumed in 2030, reaching 466.03 million SBM with a share of 20.87%, followed by LPG at 18.46%, coal at 17.49%, biomass at 15.98%, electricity at 14.31%, and gas at 12.89%.

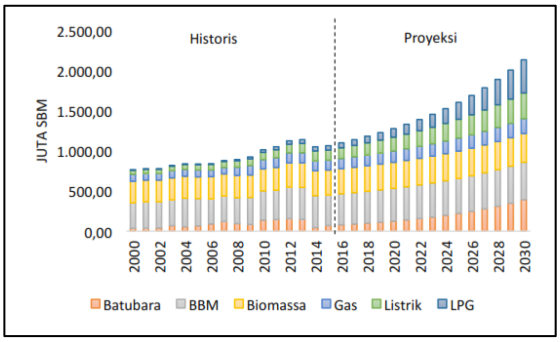


Fig. 28. Energy consumption projections by type
(Ministry of Energy and Mineral Resources (ESDM), 2016)

In 2015, energy consumption was dominated by households, accounting for 373.79 million SBM (36.18% of consumption). The following sectors were transportation (31.88%), industry (26.61%), commercial (3.70%), and others (1.64%). Meanwhile, by 2020, the dominant sector was transportation, with consumption reaching 796.46 million SBM, or 47.06%. This was followed by the household sector (27.94%), industry (19.38%), commercial (4.20%), and others (1.42%). Energy use in the commercial and transportation sectors has been increasing year by year, and by 2030, consumption in both sectors will significantly rise. This trend contrasts with the household, industrial, and other sectors, which show no significant increase.

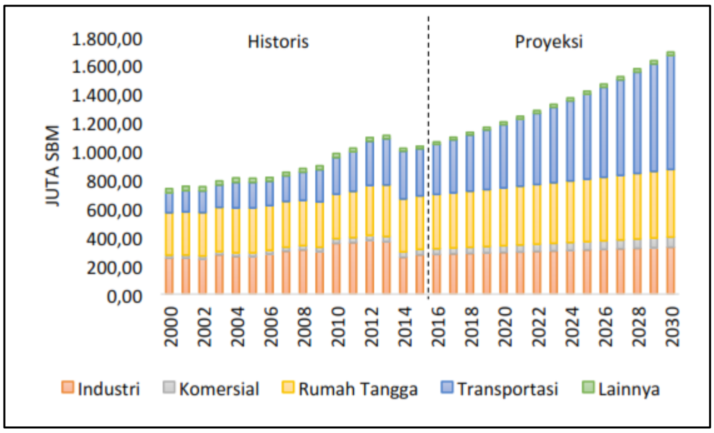


Fig. 29. Energy consumption projections by user sector
(Ministry of Energy and Mineral Resources (ESDM), 2016)

3.9 Alignment between energy fulfillment and carbon emission reduction

Based on the final energy usage data presented earlier, CO2 emissions for each sector and energy type used can be calculated. The energy sector experienced an increase in usage, growing at an annual rate of 2.43% from 2000 to 2015, as the average energy consumption rose by 2.35% per year. Below is the graph of CO2 emissions generated based on historical energy consumption data.

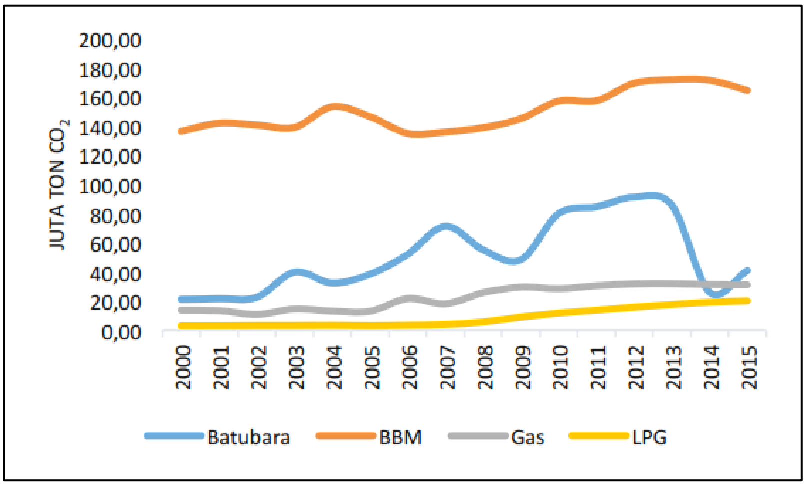


Fig. 30. Carbon emissions by energy type
(Ministry of Energy and Mineral Resources (ESDM), 2016)

By multiplying the final energy consumption for each energy type by its emission factor, it was found that emissions in the energy sector amounted to 261.89 million tons in 2015.

In Indonesia, the share was 64%, followed by coal (16%), gas (12%), and LPG (8%). In 2014 and 2015, coal emissions decreased due to a decline in consumption during those two years. However, this reduction does not necessarily reflect a reduction in carbon dioxide emissions in Indonesia. This is because the decrease in coal consumption did not mean a reduction in economic activities related to coal, nor did it indicate a shift to other energy sources, but rather a change in the reporting format for coal consumption in the industrial sector (Ministry of ESDM, 2016). The graph also shows that LPG emissions remained relatively stable over seven years. However, emissions from LPG increased since 2008 and were the highest among other energy sources. This increase was driven by the conversion from kerosene to LPG. On the other hand, this increase helped slow the rise in emissions in Indonesia.

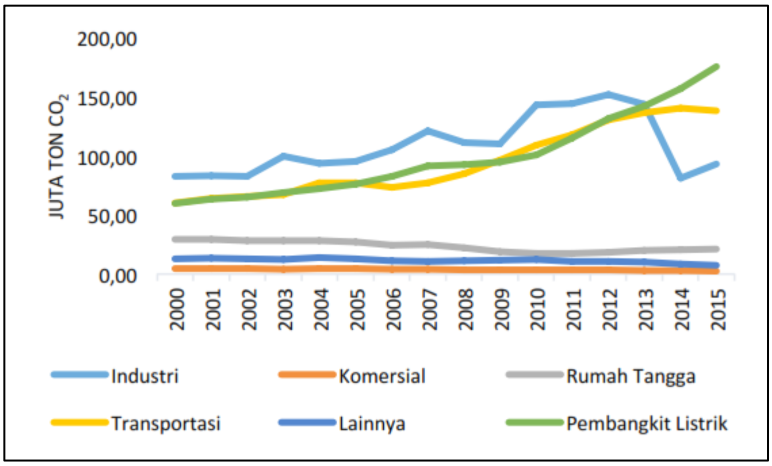


Fig. 31. Carbon emissions by user sector
(Ministry of Energy and Mineral Resources (ESDM), 2016)

CO2 emissions are produced by user sectors, including electricity users. These emissions result from the combustion of energy in each sector. In 2015, the total emissions amounted to 261.89 million tons. The transportation sector dominated the emission share (53%), followed by industry (35%), households (8%), others (3%), and commercial (1%). Emissions in the household sector were the lowest compared to other sectors, despite its highest energy usage in 2015. This was because the energy consumption in households largely relied on biomass, such as firewood, which does not produce emissions. In the transportation sector, emissions spiked due to the increasing number of vehicles each year, particularly road transportation. The availability of public transportation, whether by car or motorcycle, has made mobility easier and more affordable, but it has also contributed to higher emissions. Delivery services have also expanded significantly due to the growing trend of online shopping. Therefore, the government must prioritize the development of public transportation to mitigate and reduce the emission rate from the transportation and mobility sectors, which continue to grow. Furthermore, the industrial sector plays a role in increasing CO_2 emissions due to the use of fossil fuels. Many industries still use coal, even though the most widely used energy source is gas. As a result, emissions have risen. Moreover, changes in reporting formats also affect the higher emissions figures.

CO_2 emissions in the commercial sector are low because this sector is dominated by electricity usage. In electricity usage, emissions are calculated based on the consumption of fossil fuels. Additionally, other energy sources such as gas and LPG are used, so the increase in emissions is relatively insignificant. Similarly, in the last five years, emissions in the commercial sector have slowed down because energy consumption in this sector has decreased. This slowdown occurred as economic activities in other sectors slowed due to the decline in economic growth over the past five years.

Electricity generation has become the sector that produces the most CO_2 emissions. The consumption of electricity is significant, and its emissions are calculated based on the power plants that generate the energy and the fossil fuels consumed. Historically, emissions in this sector have surged dramatically due to rising electricity demand. This has prompted the government to improve electricity services to the public by building new power plants. One example is the construction of a 35GW power plant, projected to be completed by 2019 to increase the electrification ratio.

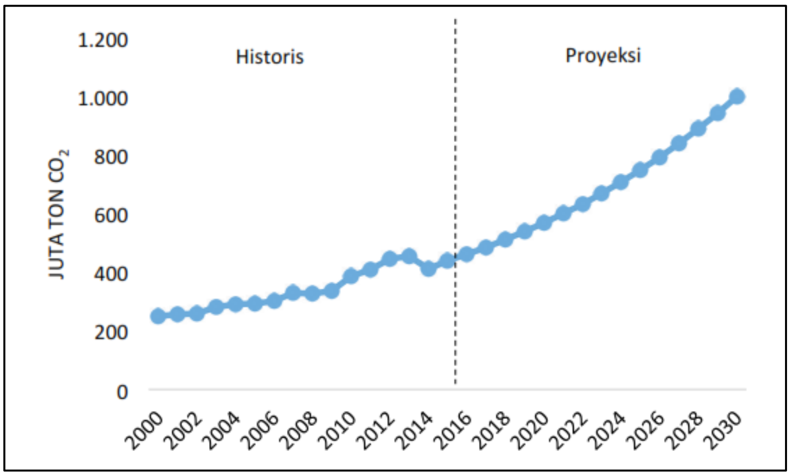


Fig. 32. Projected carbon emissions under business as usual (BaU) conditions (Ministry of Energy and Mineral Resources (ESDM), 2016)

At the baseline (year 2000), sectoral GHG emissions, including from power generation, amounted to 249 million tons of CO2 and increased to 438 million tons of CO2 by 2015. This figure is projected to continue growing, reaching 998 million tons of CO2 by 2030. The projected CO2 emissions can be seen in Figure 32.

3.10 Analysis of strategies for solving energy resource utilization problems in Indonesia

The utilization of energy resources to support economic growth in Indonesia must consider energy demand trends based on population projections, economic growth projections, environmental sustainability through carbon emission reduction, and the potential of renewable energy resources while addressing the transition from non-renewable to renewable energy sources (Shrestha & Lal, 2006). The main issues are the energy supply gap caused by oil, leading to increased oil exports as its production declines; environmental sustainability concerns due to carbon emissions from the use of fossil fuels (especially oil and coal); the growing demand for gas in domestic industries while its production remains relatively stable until 2030; and the suboptimal utilization of renewable energy. In the system dynamics model conducted by Sani et al. (2018) and Sadli (2014), it is shown that to fill the gap and focus on environmentally friendly energy, there is a need to increase domestic energy production, both fossil and renewable, in the short term as a transition period and significantly increase the share of renewable energy after the transition from fossil-dominated energy to renewable energy.

In line with the need for a transition to renewable energy and optimizing the use of fossil fuels during the transition period, the government has outlined an energy utilization strategy in the National Energy General Plan (RUEN) as follows. First, increasing the added value of energy resources and energy sources as fuel and raw materials for national industries. Second, aligning fiscal targets with energy policies. Third, gradually reducing fossil energy exports (natural gas, crude oil, and coal) and setting a deadline to begin halting exports. Fourth, maximizing the use of renewable energy, considering economic feasibility. Fifth, minimizing crude oil usage. Sixth, optimizing natural gas utilization. Seventh, using coal as a mainstay for national energy supply with cleaner technologies.

3.10.1 Non-renewable energy enhancement

Fossil fuels will continue to be the primary energy source until the completion of the transition period to renewable energy. Oil-derived energy is declining, while energy from gas and coal is relatively stable in current production. To meet the growing energy needs and reduce oil imports, efforts to increase oil production and reserves through exploration and enhanced oil recovery (EOR) technologies are essential. Efforts to enhance exploration activities to increase reserve probabilities through discovery should be supported by preparing attractive fiscal regimes for investors, simplifying related licensing processes, and offering incentives for exploration activities, especially in deep-water exploration. The choice of a flexible production-sharing contract model, whether PSC Cost Recovery (CR) or PSC Gross Split (GS), allowed by the government, can stimulate investors to engage in exploration activities in Indonesia.

For increased production through EOR methods, acceleration is needed by reviewing the most technically feasible and economically viable EOR potentials for immediate implementation. A win-win solution approach, where both the country and contractors benefit, is necessary so that EOR production enhancement efforts do not stagnate. Furthermore, the development of EOR technologies and increasing national capacity must be concretely supported by the government and industry so that in the end, locally sourced and cost-effective EOR technologies can be developed, improving the economic value for both the government and contractors. In the coal sector, future coal utilization needs to focus on domestic needs and reduce exports. One of the issues with coal utilization is its carbon emissions. For coal utilization, the obligation to use environmentally friendly technologies (clean coal technology/CCT) and high-efficiency technologies (Ultra Super Critical/USC) must be gradually implemented.

3.10.2 Utilization of renewable energy

The utilization of renewable energy in Indonesia remains limited and underutilized, highlighting the urgent need for a comprehensive strategy to facilitate the transition from non-renewable to renewable energy sources. A key issue in this transition is the economic competitiveness of renewable energy, which continues to lag behind fossil fuels. To ensure that the development of renewable energy aligns with national energy mix targets, several strategic approaches must be adopted.

One crucial step is securing a strong commitment from the Ministry of Finance through the provision of fiscal incentives. These incentives could include tax relief, accelerated depreciation for renewable energy production assets, compensation for operational losses until income is generated, and tax exemptions for the importation of machinery and equipment used in renewable energy production. These financial supports can significantly enhance the investment appeal and development prospects of renewable energy initiatives in the country.

In addition to financial measures, the State Electricity Company (PLN) must also play a proactive role by committing to an increased share of renewable energy in its electricity generation portfolio, particularly through sources such as geothermal and hydropower. To enable this transition, the government must ensure the provision of appropriate incentives that help offset the initial direct costs of renewable energy projects. With the right incentive structures, the cost of renewable energy plants can be reduced, thereby making them more commercially viable for PLN and supporting broader adoption.

Another strategic element involves price restructuring. By increasing the proportion of renewable energy in the energy mix, Indonesia can reduce its dependency on imported oil, mitigate exposure to global price volatility, and promote diversification of energy sources. Such measures also contribute to improving the country's trade balance. Moreover, with the right pricing policies, targeted incentives, and sustained political commitment—particularly toward the biofuel sector—Indonesia can achieve a more stable and self-reliant energy system.

Technological development is also critical to advancing renewable energy. At present, most renewable energy technologies in Indonesia are sourced from abroad. Although some technologies—such as small to medium-scale power generation and biogas applications—are already mastered domestically, progress is hindered by government policies that provide limited subsidies and incentives for investors in green technologies. Compared to fossil fuels, renewable energy still receives relatively minimal financial support, while investment costs remain high due to the lack of locally produced components. This imbalance contributes to the low competitiveness of renewable energy. Therefore, the government must adopt a more aggressive approach in offering substantial incentives, including pricing schemes that ensure long-term sustainability and attractiveness for investors.

Finally, consistent regulations and strong political support are essential. The implementation of clear, stable regulations regarding the use and pricing of renewable energy will provide legal certainty and foster investor confidence. This includes promoting energy sources such as geothermal, solar, biofuels, and small-scale renewable power plants. Legislative backing and political will from the government will be vital in creating an enabling environment for the growth of the renewable energy sector in Indonesia.

3.11 Reduction of energy imports through optimizing renewable energy resources

Since 2004, Indonesia has been a net importer of oil, where the volume of oil imports exceeds the amount of oil exported. The main reason for this is the continued growth of Indonesia's economy and population, which leads to increased oil consumption (Pinilih & Chairunnisa, 2019). Indonesia possesses abundant energy resources, particularly non-renewable natural resources, but the challenge lies in the fact that the production costs of non-renewable energy resources are higher than the use of fossil fuels, making the use of alternative energy sources uncompetitive. The new technologies used for extracting non-renewable natural resources are still expensive, preventing them from competing with fossil energy sources. The utilization of non-renewable energy resources as an alternative energy source can reduce fossil fuel imports. As shown in Table 3, the use of non-renewable energy resources could meet domestic energy needs up to 162,270 MW.

Table 3. Target supply of non-renewable energy resources until 2025

Energy types	2015	2020	2025	Potential
Biodiesel (KL)	1,700,000	5,784,000	16,371,559	
Bioethanol (KL)	1,112,000	3,624,000	6,876,055	49,810
Biomass (MW)	590	710	870	27,000
Geothermal (MW)	4,156	7,788	12,332	9,290
Wind (MW)	40	128	256	
Solar (MW)	85	200	250	
Small hydropower (MW)	417	760	2,486	
Large hydropower (MW)	6,069	8,940		76,170

(Pinilih & Chairunnisa, 2019)

4. Conclusions

The conclusions drawn from this paper are as follows. First, Energy Resource Mix: Currently, Indonesia’s energy resource mix is still risky in terms of supply and is predominantly dominated by fossil energy. Second, externalities of Fossil Fuels: The externalities of fossil energy, such as carbon emissions, will increase, requiring serious and realistic efforts to reduce and manage them. Third, Fossil Fuel Imports: The import component for fossil fuels used in electricity generation needs to be reduced by optimizing the use of renewable energy resources, such as geothermal energy. Fourth, System Dynamics Model Review: The review of the system dynamics model supports the need for accelerating the optimization of renewable energy utilization to achieve energy security and a low-carbon energy development strategy. fifth, Energy Mix Strategy During Transition: The energy mix strategy during the transition period should focus on continuing to increase oil production through exploration and enhanced oil recovery (EOR), optimizing gas and coal with clean technologies, and aggressively utilizing renewable energy to reduce the oil import gap, while transitioning towards renewable energy for sustainable energy development. Sixth, Government Support: Fiscal incentives from the government, energy price restructuring to make renewable energy more competitive, support for renewable energy technology development, PLN's commitment to using renewable energy with government incentives, and consistent implementation of renewable energy regulations are all essential to increasing the utilization of renewable energy. Seventh, Energy Policy: Energy policies through intensification, diversification, and conservation remain valid and should continue to be implemented.

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