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The Indonesian Government's Role in Setting Renewable Energy Targets to Reduce GHG Emissions from the Electrical Energy Sector

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ABSTRACT

Greenhouse gas (GHG) emissions are being blamed for global warming, and the Indonesian government is concerned about it. The government has proven its concern for GHG reduction by participating in the Intergovernmental Panel on Climate Change and signing the Paris Agreement. In order to meet the Nationally Determined Contribution (NDC) target in the National Energy General Plan (RUEN) 2015-2050, the government has issued regulations and plans designed to achieve the objective of producing up to 31% of the nation's electrical energy from renewable sources by 2050. The RUEN transcription in the General Plan of Regional Energy (RUED) will be implemented in the RUED of West Papua (RUED-P), which is expected to reach the target of 33% of the energy production from renewable sources by 2050. The main issues with implementing NDC targets in RUEN and RUED-P are related to time and costs. This paper investigates the effectiveness of current and proposed government regulations in achieving Indonesia's NDC target by 2030 through the implementation of RUEN and RUED-P in the province of West Papua. The simulation results show that the target of achieving the NDC target of a 29% reduction in GHGs through RUEN can be surpassed. The potential exists to achieve a reduction of 54,363 tons CO2e (or 30.01%), compared to the 'business as usual' (BAU) scenario of 77.619 tons CO2e. However, the NDC target of a 41% reduction by 2050 will not be met as implemention of the West Papua regional scenario via the RUED-P will result in a GHG reduction of only 55,393 tons of CO2e, or 28.63% under this scenario. By imposing a 2030 target for energy production from renewable sources amounting to 33% of total generating capacity under RUED-P, the NDC target can actually be exceeded. Under every scenario, the state-owned electric company (PLN) operates at a deficit under current customer pricing. For this reason, the government needs to increase the basic electricity tariff to IDR 2,500 per kWh in order to support PLN operations and not burden the state's budget by subsidizing PLN's losses.

Keywords: greenhouse gas, renewable energy mixture, Paris agreement, nationally determined contribution, West Papua.

INTRODUCTION

The continuous rise in the world population has led to massive energy usage due to human activity and industrial expansion. The ever-increasing demand for power has been met by burning fossil fuels as the primary source of world energy (Seutche et al., 2021). A key adverse result of this burning activity is carbon emissions, which are the primary cause of rising global temperatures. As the amount of remaining fossil fuel have been diminishing, prices for these dwindling resources have been rising dramatically. Hence, the search has been underway for some time for alternative energy sources such as hydropower, solar and wind energy, and biomass (Tantiwatthanaphanich & Zou, 2016) that will make it possible to continue to fulfill energy demands that increase every year. These renewable energy sources show promise for being able to meet future world energy demand, and research in this area has matured. Hence, many efforts have been made to integrate the electricity generated from renewable energy sources into the power grid.

Human activities, especially those that produce greenhouse gases (GHG), may pose a danger to the world's environment since elevated levels of GHG can lead to climate change. Carbon dioxide gas is the primary type of GHG emitted into the atmosphere (Choi et al., 2022), and GHGs are primarily to blame for the rise in average global temperature, which increased by 0.85 degrees Celsius between 1880 and 2012, according to the Intergovernmental Panel on Climate Change's Fifth Assessment Report (AR5) (Yang et al., 2016).

On December 12, 2015, representatives of approximately 196 countries met in Paris to adopt an agreement to reduce GHG emissions in order to achieve global temperature control. The countries agreed to submit, by 2020, their Nationally Determined Contribution (NDC) plans, including proposed actions to reduce the greenhouse gas emissions and develop resilience with respect to the impacts of rising temperatures.

The Paris Agreement took effect on November 4, 2016. As a signatory to the agreement, Indonesia committed to reducing global warming by reducing emissions as soon as possible. Even before the agreement was signed, the Indonesian government had attempted to lessen GHG production through the National Energy General Plan (RUEN). Following that the initial adoption of RUEN, several revisions were undertaken to adapt the agreement as recorded in RUEN 2015-2050 (Presidential Instruction, 2017a), which is outlined in the Regional Energy General Plan (RUED) for 34 provinces in Indonesia.

West Papua Province was formed in 2000 after being separated from Papua Province by Statute 45 of 1999 (Law No. 45, 1999). The two provinces are currently the poorest in Indonesia, highlighting the inequality of development in the country. In an effort to promote development in these two provinces, the government set six development priorities by Presidential Instruction No. 9 of 2017 (Presidential Instruction, 2017b), which concerns the acceleration of development in Papua and West Papua. The development priorities are: (1) increasing the quality and access to education, (2) improving the quality and access to health, (3) improving social security and social welfare, (4) ensuring adequate housing, clean water, and sanitation, (5) local economic development, and (6) connectivity. This set of priorities was later updated by Presidential Instruction No. 9 of 2020 (Presidential Instruction, 2020).

Concerning low-carbon development, in 2019 the province of West Papua was declared a sustainable development province that prioritizes conservation aspects in its development (Hendri et al., 2021). This declaration means that local governments will refer to efforts to conserve, protect, and exploit biodiversity and ecosystems when implementing development programs. Other initiatives have also been carried out in West Papua Province, such as the implementation of low-carbon development and digital-based village development.

The NDC targets for emissions reduction supported by the Indonesian government are set at about 29% with some effort, and 41% with external assistance, by 2030 (Hendri et al., 2021). Some regulations have been promulgated to help achieve these goals, especially in the electrical energy production sector. To investigate the effectiveness of these regulations, simulations need to be conducted based on the target models. If the simulations show that the targets will not be achieved within the targeted time frame, the government is obliged to revise the plans, or add supplemental regulations to support target achievement.

System dynamics is a problem analysis technique that imitates a complex, dynamic, non-linear, and feedback-equipped system or abstraction form (Tjolli et al., 2021). A system dynamics model is capable of accepting system dynamics that require some interventions that need to be integrated throughout the simulation, increasing the model's complexity. Such models have been used successfully to help overcome problems of deforestation (Hendri et al., 2021), solid waste management (Prabawardani et al., 2021), eco-industry development (Wurarah et al., 2021), and electrical energy supply and demand (Oxa & Erma, 2012) as well as being used for analyzing and solving complex policy problems (Malbon & Parkhurst, 2022).

This study aims to perform simulations in system dynamics modeling to investigate the effectiveness of government policies with respect to implementation of the Paris Agreement, and to provide local government strategies to meet the NDC target for reducing production and emission of GHGs. This research will be helpful to governments, organizations, local communities, and those who participate in providing electricity for society and industry. The West Papua Province is one of three provinces in Indonesia that have not finished development of their RUEDs yet. Therefore, a complete review of renewable energy implementation in the West Papua Province through the planning RUED (RUED-P) is provided in this paper.

Research Question

- How effective is the the RUED-P in helping the government to meet the NDC target?
- When are interventions needed to reach the NDC targets?
- What are the economic benefits of the adoption of renewable energy with respect to government expenditure?

Research Objectives

The objectives of this research were as follows:

- to identify the renewable energy scenario that best fits the local capacities, so that local governments can consider optimal development of the RUED in order to meet the NDC targets.
- to provide some insights about possible interventions to enhance the integraton of renewable energy into the power grid.
- to project likely GHG emissions and economic value of power generation operations.

LITERATURE REVIEW

System dynamics accommodates the dynamic complexity of a system that is simulated in a model, typically in an abstract form. This dynamic complexity, which is a phenomenon whose structure is formed by interdependent elements and naturally has a dynamically complex character, is characterized by:

1. frequently encountered facts that reveal the failure of policies intended to help overcome a problem or address the existing situation;

2. the existence of a decision that can produce the desired dynamics only in the short term, while, in the long term the decision produces unwanted behavior, or vice versa; and

3. a decision that can improve the behavior of a particular sector in accordance with its objectives, but which will disrupt the behavior of other sectors (Malbon & Parkhurst, 2022). Some publications that use system dynamics to solve the problems are discussed in the following paragraphs.

According to Hendri et al. (2021), the West Papua tropical forest is one of the mega biodiversity areas in the Sahul Shelf Eco-region. For this reason, West Papua is important to maintaining Indonesia's sustainability and in achieving its NDC target of 41%. Even though it has been identified and targeted as a province for sustainable development, forest degradation in West Papua averaged 1.29% per year in the

2010–2018 period due to the conversion of natural forests to managed forests. The study results conclude that it can be achieved by sacrificing a maximum of 6.59% of gross regional domestic product (GRDP) by 2030 (Hendri et al., 2021).

Solid waste produces many of the GHGs that cause global warming, and as GRDP increases, the amount of solid waste generated also increases. Prabawarnani et al. (2021) found that West Papua will produce 3.7 million tons of waste and 1.1 million tons of CO2 by 2030. As a result, West Papua should manage its waste at a rate of no more than 118,297 tons per year in order to meet the target of 29% of the NDC.

Wurarah et al. (2021) found that the manufacturing industries in West Papua account for 3% of the GRDP. These industries will contribute 72,000 tons CO2e in 2030. For this reason, local governments need to seek eco-industry development (EID) to suppress GHGs. This effort can limit GHG emissions to 57,000 metric tons CO2e; however, doing so comes with the risk of an economic contraction of IDR 2,000 billion.

A system dynamics model to analyze the demand and supply of electrical energy for the industrial sector was developed by Oxa and Erma (2012), and applied to the calculation of electrical energy demand in the province of East Java. The authors found that the region may face shortages in electricity supply by 2025 and, thus, need to increase its generating capacity.

Recently Malbon & Parkhurst (2022) apply system dynamics to assist in the analysis and solving of complex policy problems. They examined three concerns raised by public policy researchers in the implementation of system dynamics to policy making: (1) the bound rationality inherent in decision-making making, (2) selection and construction of policy problems and solutions and (3) representation and accountability of stakeholders involved in selecting and applying evidence. By emphasizing some conceptual points of intersection between complexity thinking and public regulations debates regarding the use of evidence in policy making, involving restricted rationality, the interaction between evidence selection and problem definition, and issues of accountability and illustration concerning who belongs in the system dynamics modeling process, they found that such an outlook might naturally lead to further considerations on how to institutionalize the use of such technologies, and the democratic implications of doing so. As policymakers continue to engage in modeling with system dynamics and ther comparable tools, it will be crucial to pay attention to issues concerning the choice and application of this evidence (Malbon & Parkhurst, 2022).

Previous studies have provided an overview of GHG reduction efforts in the forestry, economic, and waste sectors, as well as the use of dynamic systems to solve complex problems in the electricity and political sectors. However, specific GHG issues related to the supply of electrical energy have never before been discussed, despite the fact that the energy sector is Indonesia's second largest contributor of GHGs after the transportation sector. Thus, it is important to discuss the integration of renewable energy sources in an effort to reduce emissions in this sector. Therefore, this research focuses on simulating policy formulation leading to different outcomes with respect to types and levels of alternative energy sources in RUEN and RUED-P scenarios to meet the Indonesian NDC target through system dynamics models.

RESEARCH METHODOLOGY

Model description

In this modeling, the demand for electrical energy in West Papua province is influenced by population growth and gross regional domestic product (GRDP), with an indicator of electricity consumption that states the level of industrialization that has been achieved. The ability and capacity of each available power plant is determined by how much electricity is needed. The power and generating capacity are related to the installed capacity in 2021.

The final results of the electrical energy demand modeling identify how well the existing electricity infrastructure can support electricity demand in this province. The estimation of electricity demand is related to the trend (behavior) of electricity consumption in each sector. The model is made based on historical data to optimize the electricity demand forecast so that it can produce more accurate and reliable results.

System Modelling

Stock-flow diagrams (SFD) are used to model system dynamics. The model consists of stock (level) and flow (rate) variables inside the SFD. The effect of time on the relationship between variables is taken into account in the SFD.

The RUEN and RUED-P scenarios are designed using the "business as usual" (BAU) model to determine GHG emissions, income, and outcomes of electrical production in West Papua Province while accounting for electricity demand. The models are detailed as follows.

1. BAU model

This model shows the relationship between GRDP, population, and energy demand. The demand is then divided among the installed power plants, and GHG emissions are calculated based on the thermal power plant fuel consumption using fossil fuels.

2. Scenario 1 model (RUEN).

Based on the RUEN target, 31% of the power grid in this scenario comprises a mix of renewable energy sources.

3. Scenario 2 model (RUED-P)

West Papua province's RUED has not yet been issued. Therefore, in this scenario, the RUED plan for this province (RUED-P) is designed. The mixture of renewable energy is slightly higher than in the RUEN-P scenario, accounting for 33% of the total production capacity.

Model validation

In order to avoid any potential errors that might arise during the modeling scenario of the SFD, the designed model must be validated. The validation process is intended to ensure that errors will be eliminated, the model will be sufficiently accurate, and the simulation will align with expected reality. The absolute mean error (AME) is chosen to validate the model. It can be formulated as follows (Tjolli et al., 2021). The AME limit value of about 30% is considered strong enough to support the validation model process.

$$AME = \left(\frac{S_i - A_i}{A_i} \right) 100\% \tag{1}$$

where A is the actual value, and S is the value of simulation, while subscription *i* represents the number of data sequences.

Model limitations

Investments in the procurement of large-power electricity in the state-owned and operated electric company (PLN) grid system are generally carried out based on electricity supply contracts so that investment profits can be calculated based on the contract value and not on the basic electricity tariff, which is determined separately by government decree. Thus, the simulation on the built model can only be carried out to calculate PLN's income and expenditures to determine whether the state electricity company takes a profit or loss.

GHG emissions

Three main gases that contribute to GHG emissions are carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). Carbon dioxide is the primary GHG pollutant.

The method used to calculate the emission is based on Rizaldi et al. (2012), and is simplified from the IPCC Guidelines 2006 (Eggleston et al., 2008) within tier 1 and tier 2. The formulations are given in Equations 2 and 3, including energy consumption E_c, fuel amount F_a, and some constants of caloric C_a and emission factor E_f provided in Table 1.

$$GHG = E_c \; E_f \tag{2}$$

$$E_c = F_a \; C_a \tag{3}$$

RESULTS AND DISCUSSION

Model development

The greenhouse gases emitted through the generation of electrical energy are modeled and implemented in the system dynamics modeling. A stock-flow diagram of the model is presented in Figure 1. Data for the model is taken from a number of sources: West Papua in Figures 2010 to 2021 (Biro Pusat Statistik [BPS], 2010), Electricity Statistics 2010 to 2021 (Anonymous, 2010), and State Electricity Company (PLN) Statistics of 2020 (Perusahaan Listrik Negara [PLN], 2021). Some of the initial values used in the simulation are given in Table 2.

In system dynamics modeling, the designed model is based on the real world, so the availability of data is a crucial issue. For this reason, several assumptions will be made, and they play essential roles in overcoming any lack of data needed for the modeling. The list of assumptions made for the energy demand models is as follows:

- Population and GRDP growth rates are 3.36% and 4.08% per year, respectivelly.
- Electricity prices and electricity per capita remain constant at IDR 1,504.71 per kilowatt-hour (kWh) and 7.8378e^{-9} GWh/person, respectively.
- Every generator is assumed to work at 75% of its installed capacity, with the exception of solar power generation, which is assumed to produce at about 25%.
- Based on data from 2020, the total installed capacity in 2021 is estimated to be 459.55 MW.
- The state electrical company (PLN) controls all power plants connected to the grid, including rented and private power plants.

Table 1

Emission and Caloric Constant

Fuel type	Caloric	Emission factor
Diesel (HSD)	36x10-6TJ/litre	74100 (liter/TJ)
Natural gas	47.3x10-6TJ/kg	64200 (Kg/TJ)
Coal	18.9x10-3TJ/ton	56100 (kg/TJ)

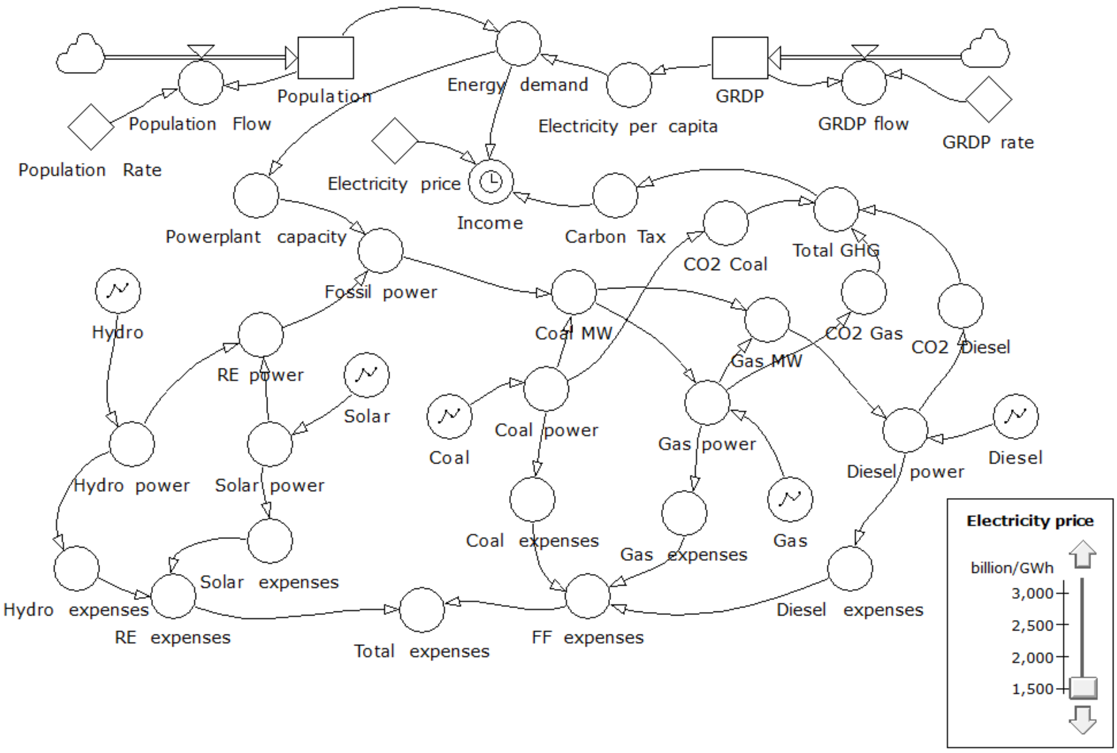
Table 2

Initial Values

Variables (unit)	Baseline value	Resources
Population (Persons)	1,134,068	2020 West Papua in Figures
GRDP (Billion IDR)	61,592	2020 West Papua in Figures
Electricity price (IDR/kWh)	1,504.71	Average price

Figure 1

Stock Flow Diagram



As shown in Figure 1, population and GRDP are growing, and this growth influences energy demand. The assumption is that when the GRDP increases, people will spend more money on electricity due to increased prosperity. There is no specific data on how much money is spent in the electrical energy sector under the influence of GDRP, so it is assumed to be growing at the stated rate. Both population and GRDP should be validated since growth might be nonlinear.

Power plant capacity is the result of energy demand in a year. The capacity is then allocated among renewable energy sources, and the remainder is assumed to be provided by fossil fuel plants. There are three fossil fuels used, and the model prioritizes them, in order: coal, gas, and diesel. This is because diesel power plants are scheduled to be phased out in favor of coal power plants, which are less expensive than gas powered plants. CO2 emissions are then specifically projected for each type of generator, and the result is fed back to reduce income since, starting in 2022, carbon taxes have been applied at a rate of approximately IDR 30,000 per ton (Tax Harmonization, 2021).

In general, this dynamic model system shown in Figure 1 will meet the energy demand based on population growth and energy per capita, which are calculated based on the GRDP growth in the West Papua region. Furthermore, this demand will be allocated to each generator according to real-world conditions and government interventions through RUEN and RUED-P. The energy generated by each power plant in the specified scenario will have an impact on the production of GHG emissions. These GHG emissions will be taxed based on government tax harmonization regulations (Tax Harmonization, 2021), with the taxes being charged to each generator's operating costs. Finally, the expenses and income generated by the operation of the power plants will be calculated for each scenario.

Renewable energy planning of RUED-P

Hydropower offers a promising solution for West Papua Province in implementing RUED since rain forests cover about 60% of its total area. However, customary rights and forest tenure comprise a complex social issue in hydropower development. On the other hand, small-scale hydropower may be implemented, and about 6 megawatt (MW) micro-hydropower plants are planned for 2025.

Wind energy is only effective in the areas along the west coast of the West Papua Province. However, in these areas, the wind may not reach the average speed of four meters per second required to turn the wind propeller. Therefore, the capacity planned for wind power in 2030 is about 12 MW.

Solar power offers a promising and flexible solution for West Papua Province since it is located close to the equator, which ensures substantial solar irradiance year-round. By 2050, solar generation is expected to reach 5,000 MW of installed capacity; however, this is a high-cost source of energy.

Other renewable energies have the possibility of being implemented in West Papua Province, such as geothermal, tidal wave, and biomass. Due to the high level of technology and investment required, these types of energy production may not be realized in the near future.

Model validation

It is important to make a precise model so that an accurate and meaningful simulation results are achieved. To ensure that the model is accurate enough, it has to be validated. Table 3 summarizes the number of simulations and collected data that were used for validating the model.

The provided AME values are only 2.84% of GRDP and 1.05% of the population, which is less than the 30% standard for model validation given in the previous section. Therefore, the designed models are valid for use in the simulations.

Simulation and analysis

Based on the stock-flow diagram in Figure 1, the simulations were carried out for all the designed scenarios of Business as Usual (BAU), RUEN (SC1), and RUED-P (SC2). The results of the simulations are given in Tables 4 and 5.

Table 3

Data Validation

Year	GRDP		Population	
	A_i	S_i	A_i	S_i
2010	41,362	41,362	757,700	757,700
2011	42,867	43,512	789,300	783,159
2012	44,423	45,775	816,300	809,473
2013	47,694	48,155	828,300	836,671
2014	50,260	50,660	849,800	864,783
2015	52,346	53,294	871,500	893,840
2016	54,711	56,065	893,400	923,873
2017	56,907	58,980	915,400	954,915
2018	60,465	62,047	952,400	987,000
2019	62,071	64,001	974,760	1,020,164
2020	61,592	67,182	1,134,068	1,054,441
AVG	52,245	53,730	889,357	898,729
AME	0.0284		0.0105	

Table 4

Target Mixture Fuels

Year	Population (Person)	Energy demand (GWh)	Plant capacity (MW)	GRDP (Billion IDR)
2,020	1,134,068.00	547.47	62.45	61,592.00
2,025	1,337,832.06	788.79	89.98	75,224.75
2,030	1,578,207.50	1,136.47	129.65	91,874.96
2,035	1,861,772.48	1,637.41	186.79	112,210.52
2,040	2,196,287.09	2,359.15	269.13	137,047.14
2,045	2,590,905.74	3,399.03	387.75	167,381.09
2,050	3,056,427.62	4,897.27	558.67	204,429.15

Table 5

GHG Emissions

Year	GHG emission (TonCO2e)			GHG Reduction (%)	
	BAU	SC1	SC2	SC1	SC2
2,020	33,969.16	30408.91	35,181.81	10.48	-3.57
2,025	51,752.78	40311.75	36,289.58	22.11	29.88
2,030	77,619.83	54,326.33	55,393.88	30.01	28.63
2,035	106,308.38	73,622.90	74,189.24	30.75	30.21
2,040	156,222.67	107,196.38	106,890.68	31.38	31.58
2,045	217,336.71	155,568.51	154,006.40	28.42	29.14
2,050	341,645.82	201,594.06	198,221.71	40.99	41.98

Table 4 displays the dependent variables that comprise the general results of the scenarios. The population growth was 3.36%, and GRDP rate of growth was 4.08%. As shown in this table, the population in 2050 is projected to be three million people, which is roughly triple the population in 2020. As a result of this dramatic population growth, energy demand will rise to 4,897 gigawatt-hours (GWh) by 2050; therefore, power plant capacity will have to increase to 558 MW. Similarly, GRDP is predicted to increase by about IDR 204,429 billion.

Total GHG emissions and income from the operation of electrical energy generation are shown in Table 5. By implementing the RUEN, about 140,051.76 tons of CO2e comprising approximately 40.99% of GHG emissions are eliminated in 2050.

During the planning period, renewable energy is integrated into the power grid, comprising 33% of total capacity, and resulting in a reduction in GHG emissions of approximately 143,424.11 tons CO2e, or 41.98%. Due to the assumption of no change in electricity prices, the income per generated unit of energy is constant in all scenarios, totaling about IDR 7,368 million in 2050.

Business as usual *(*BAU*)*

The results of the "Business as Usual" simulation are graphically presented in Figure 2. The installed capacity in 2020 may not support the needs of electric energy until 2050. The integration of power plants, including solar, coal, and hydropower plants, which has been planned since 2025, can support the lack of electrical energy in this area.

In this scenario, all power plants using renewable energy and coal power are scheduled to work at maximum capacity in 2023, as shown in Figure 2(a). The remaining demand will be met by diesel and gas power plants. As the gas plants reach maximum capacity in 2047, diesel power will continue to meet demand as required.

The GHG emissions of coal, gas, and diesel power are given in Figure 2(b). The emissions are dominated by diesel power plants, which generate 207.17 megawatts (MW) and emit approximately 141,475.5 tons CO2e. As a result, total GHG emissions in 2050 are 341,645.82 tons CO2e.

Scenario 1 *(*SC1*)*

Under scenario 1, RUEN's plan to meet the NDC is accommodated by including renewable targets in fulfilling energy demand. This scenario is summarized in Table 6.

Figure 2

BAU Results

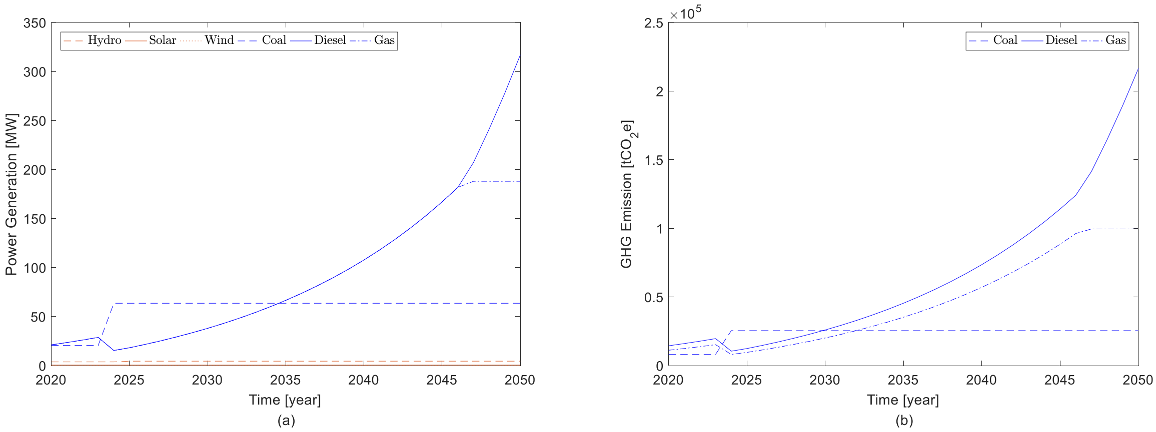


Table 6

Targeted Use of Energy Sources

Scenario	Fuels	Target (%)			Plant Capacity (MW)		
		2015	2025	2050	2015	2025	2050
RUEN	Coal	26	30	25	26	26	26
	Gas	23	22	24	580	1300	5000
	Oil	46	25	20	95	95	0
	Renewable	5	23	31	13	63	5018
RUEN-P	Coal	0	0	0	26	26	26
	Gas	21	88	67	58	1300	5000
	Oil	71	7	0	95	95	0
	Renewable	8	25	33	13	63	5018

The RUEN is applied to scenario 1 in this simulation. While the simulation starts in 2020, using the 2015 target, the implementation is carried out between 2025 and 2050,. implementing the RUEN targets for both 2025 and 2050. Figures 3(a) and 3(b) graph the simulation results, which show a slight change in 2025. The other changes, in 2030, are due to termination of diesel power generation, so this lost capacity will be replaced by solar and wind power, while gas power handles the rest.

In this scenario, the power generation is dominated by gas power, at about 365.72 MW in 2050, while it emits about 193,674.46 tons CO2e. At the end of this simulation, more solar power is integrated to meet the target of 33% renewable energy sources on the grid, as shown in Figure 3(a) by a dip of the solid red and dash-dot blue curves.

Scenario 2 *(SC2)*

In scenario 2, it is planned that renewable energy sources will comprise about 33% of total capacity in 2050. It can be seen that, by executing this scenario, the heavy reliance on gas power can be decreased, and total GHG emissions can be effectively decreased, as shown in Figure 4(b).

It is evident from Figure 4(a) that gas power dominates the simulation, though gas powered energy production decreases following the integration of 25% and 30% renewable energies in 2025 and 2050, respectively. The only remaining thermal power plants in this scenario,

Figure 3

RUEN Results

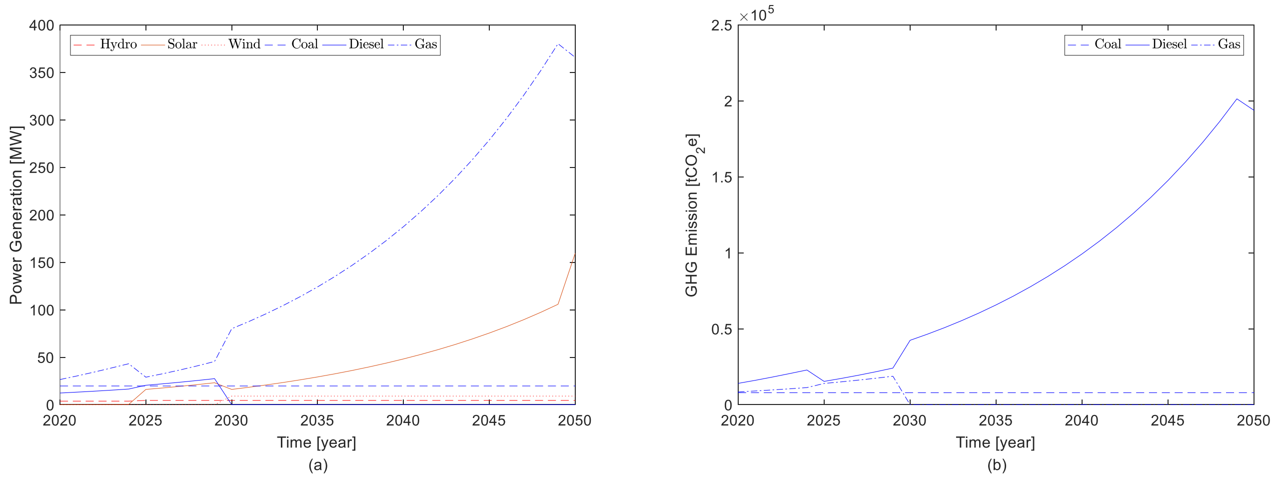
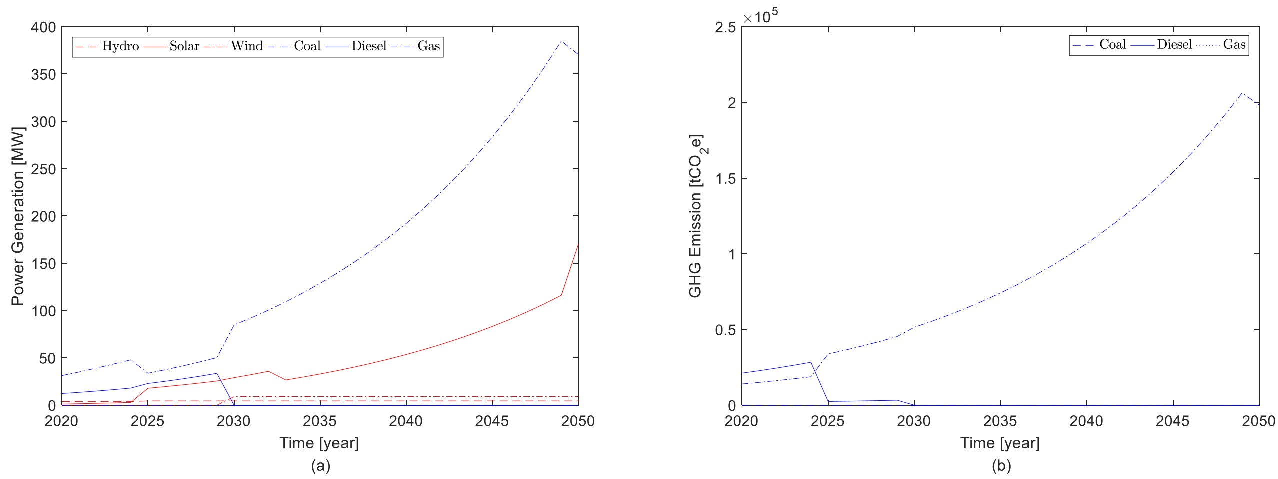


Figure 4

RUED-P Result



after the termination of diesel power in 2030, are gas powered. These plants emit 198,221.71tons CO2e to generate 370.46 MW of power.

Cost and income

Figure 5 graphically displays the income and expenses for power generation in all scenarios. It is evident from these graphs that the income is below expenses in all scenarios, meaning that the state electrical company (PLN) operates at a deficit in under every set of simulated conditions. Over the course of 30 years, this deficiency is much more pronounced under BAU than it is in the RUEN and RUED-P scenarios, as evidenced by the gaps between income and expenditure visible in Figure 5(a).

In the BAU scenario, , the electricity company almost breaks even in 2025, where the blue curve almost touches the income area. In this year most of load (about 63.64 MW) is supported by coal power. Beyond that point, the company continues to lose money and requires outside assistance or subsidies to continue operating. In this scheme, primary generators are powered by diesel and gas and supplemented by small coal generators. The coal generators are expected to reach maximum capacity in 2025, at which point the total demand should be handled by diesel and gas generators until the gas generators reaching maximum capacity in 2047.

The operation of the power plants under BAU demonstrates that PLN can never achieve a surplus in its operations as the population grows exponentially. The rise in expenditures creates a large gap between costs and income as shown by the large gaps between the income area and the blue curve in Figure 5(a).

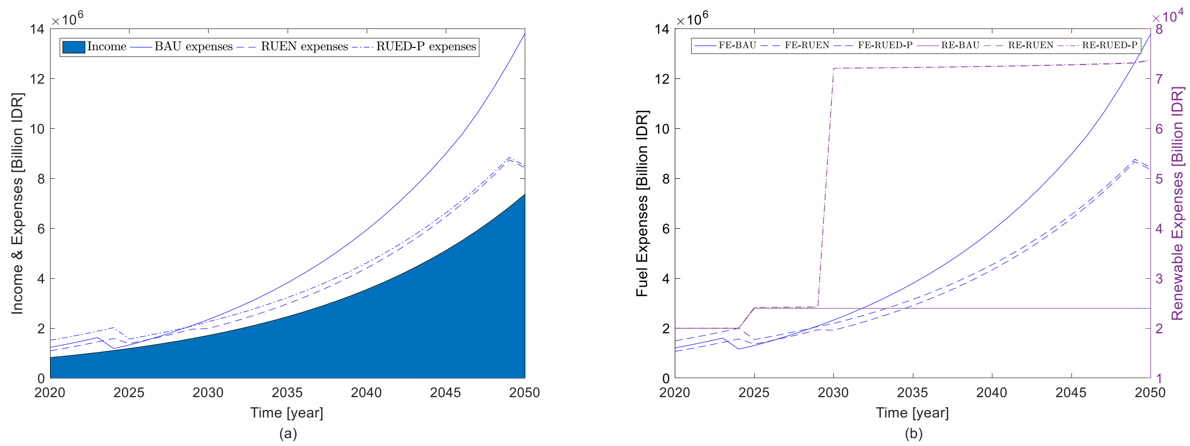
The operation of renewable energy in both scenarios 1 and 2, on the other hand, reduces expenses. The curves of red and orange indicated that the RUEN scenario is more effective at cutting down expenses in the beginning, but that RUED-P offers the most cost-effective path to achieving targets between now and 2050.

In both scenarios 1 and 2, reducing the use of diesel energy and increasing the use of renewable energy sources results in lower spending beyond 2025. Furthermore, with the same scenarios and an increasing demand load, spending on electricity generation can be further reduced. Figure 5(b) shows that spending on renewable energy increases dramatically in scenarios 1 and 2 beginning in 2030, when renewable energy plants handle more than 30% of total demand. As a result, the consumption of fossil fuels is reduced.

The green and purple curves in Figure 5 show that eliminating diesel power will save money by 2030. The figure also demonstrates that these scenarios result in financial losses annually until finally reaching a high penetration of solar power in 2050. The losses happen because the standard operation of solar power costs IDR 11,317.97/kWh (PLN, 2021), which is almost ten times the recent electricity price charged to customers.

Figure 5

Income and Expenses



GHG Reduction

The reduction in GHGs in scenarios 1 and 2 tends to be more pronounced every year, even though an increase of about 3.57% occurs in the early stages of scenario 2. This increase is triggered by the termination of coal power, while at the same time diesel power is forced to supply up to 71% of demand. However, the Scenario 2 development trend is quite positive because the target of 29% reduction can be met or exceeded in 2025, while this target can't be achieved in Scenario 1 until 2030.

Overall, the national strategy to achieve the NDC for emission reductions of 29% in 2030 can be exceeded by achieving 30.01% in scenario 1. Nevertheless, the NDC target of reducing emissions by 41%, which should be achieved in 2030 under scenario 2, can only be realized in 2050 under scenario 1. This shows that the West Papua regional strategy to help realize Indonesia's national NDC has been quite effective, but needs to be adjusted so that the target of 41% emission reduction in the NDC can be realized in 2030.

In 2030, it will already be possible to supply 33% of the demand using solar power, which, according to the plan, can only be announced in 2050. With possibility of meeting the target of 33% demand load on RUED-P in 2030, the national NDC of 41% in the West Papua region can be realized. In the event that this scheme is executed, the GHG reduction in 2030 will exceed the target by about 41.5%.

Figure 5 displays the income and expenses for power generation in all scenarios. It is evident from the figure that the income is below expenses all scenarios, meaning that the state electrical company (PLN) is always in deficit in operations. This deficiency is lessened in the RUEN and RUED-P scenarios, as evidenced by the smaller gaps as compared to the BAU expenses represented by the solid dark blue line.

RECOMMENDATIONS

Based on the simulations carried out, the NDC emission reduction target of 29% can be achieved in both scenarios 1 and 2. However, the 41% target is not been met in Scenario 2 due to the lower reliance on renewable energy sources, despite the fact that sufficient renewable infrastructure will be available by 2030 to support this target. For this reason, it is recommended that local governments set the target for renewable energy sources at 33% of total capacity in 2030 instead of the initial proposed target of 21% so that a more aggressive objective can be realized by 2050.

Economically, it is well known that PLN is rarely profitable in its operations due to electricity price regulation, with the price per KwH maintained at less than IDR 2,000. The low household incomes of the Indonesian population accounts for the low price of electricity; therefore, the government has to provide subsidies to the PLN. The central government should have set a minimum electricity tariff of IDR 2,000 per kWh beginning in 2020 so that PLN revenue would slightly exceed expenses. However, it is recommended that the tariff be increased to IDR 2,500 per kWh so that PLN can have a surplus, and not depend on state subsidies. This may be difficult for the government because such a move would be meet with opposition and would cause domestic turmoil, affecting many sectors. To avoid this dilemma, the government can increase the tariff by IDR 100 per year. This type of staged increase is quite realistic and can be achieved because people's financial welfare has been increasing in line with rising regional GRDP. Thus, it is hoped that a tariff of IDR 2,500 per kWh can be achieved within ten years, allowing PLN to operate independently and for government subsidies to be phased out without causing significant social or political upheaval.

Planning for 5,000 MW of solar power in 2050 under RUED-P is a bit excessive because it is possible that this level of generated power will not be required. Based on the simulation, about 159.51 MW of solar power will be used in 2050, or around 997 MW at installed capacity, with an average efficiency of 16%. Thus, it is estimated that around 4,003 MW of installed solar power will be redundant and unusable. Moreover, a large on-grid solar power system connected to the power grid might trigger a stability issue that could be dangerous for grid operations.

CONCLUSIONS

In this paper, models for integrating renewable energy into the power grid are provided, including the business-as-usual (BAU), RUEN, and RUED-P scenarios. The models are based on the actual condition (BAU), and then they are expanded to account for interventions under scenarios 1 and 2.

The RUEN intervention can eliminate a total of 120,524 tons CO2e GHG emissions in 2050, which is a reduction of approximately 36.59%. In the same way, intervention under RUED (RUED-P) can eradicate about 39.83% of the GHG emissions, or about 131,256 tons CO2e.

The interventions under RUEN and RUED-P may not be ttoally cost effective for the electrical company since the company is projected to operate at a deficit in every simulation. On the other hand, while the state-owned company may lose money, government policies, both national (RUEN) and local (RUED-P), will successfully reduce GHG emissions in the energy sector in line with the Paris Agreement.

The simulation results show that in scenario 1, the NDC target of 29% in 2030 can be exceeded through central government intervention, actually reducing emissions by 30.01%, or 54,326 tons CO2e. On the other hand, in scenario 2, the regional government's strategy only achieves a reduction of 28.63% or 55,393 tons CO2 in 2030, which is still 12.37% short of the NDC target of 41%, which cannot be achieved before 2050. As a result, intervention is required to raise the proportion of power generated from renewable sources to 33% by 2030. It has been demonstrated that incorporating renewable energy into PLN's generation operations can reduce costs by more than 50%; however, PLN will continue to lose money as long as the basic electricity tariff remains relatively low, despite the imposition of a carbon tax of IDR 30 per ton CO2 in 2022.

Based on the simulation results, the following recommendations are given:

1. The West Papua regional government needs to increase the 2030 target for the amount of energy from renewable sources in the RUED-P to 33% of total generating capacity from the current target of only 21%.

2. The local government's target of achieving an installed capacity of 5,000 MW in 2050 should be reviewed because, in that year, demand for power from solar generation is expected to amount to only 997 MW.

3. To stabilize PLN's financial performance, the central government needs to gradually increase the basic electricity tariff to IDR 2,500 so that PLN's operations are no longer dependent on state finances through government subsidies.

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