International Journal of
Sustainable Energy Planning and Management

An Analysis of the Impact of the Covid-19 Pandemic on the Implementation of Renewable Energy in the Supply of Electricity

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ABSTRACT

The Covid-19 pandemic has affected all activities, including the electricity supply. As a developing nation, Indonesia is also severely affected by the diversion of significant resources to combat Covid-19. On the other hand, Indonesia is committed to reducing emissions in the energy sector, which includes implementing renewable energy technologies to provide electricity. This article examines the effect of the post-covid-19 pandemic situation on the implementation of renewable energy in the electricity supply. The case study examined is the electricity supply in the province of Yogyakarta, which obtains its electricity from outside the province but has multiple forms of renewable energy that can be optimized in the electricity supply. There are three scenarios discussed: the current target scenario, the lower target scenario, and the supply security scenario. The current target scenario includes predetermined renewable energy goals. The lower target scenario is used to characterize Covid-19's impact on the implementation of renewable energy. The supply security scenario is the most optimistic, as it optimizes the use of renewable energy in the electricity supply while ignoring the impact of the co-19 pandemic. The current target scenario is used as a benchmark against which the other two scenarios are compared. Comparing the lower target scenario to the current target scenario, the lower target scenario results in 9.6% lower capital costs and 4.1% higher greenhouse gas emissions. The least greenhouse gas emissions are produced by the supply security scenario, but the capacity costs are the highest.

Keywords:

Covid-19;
GHG emission;
Low emission analysis platform;
Planning cost;
Renewable energy;
Scenario

http://doi.org/10.54337/ijsepm.7659

1. Introduction

The COVID-19 pandemic has had a significant impact on national and international economic activity. According to the Organization for Economic Cooperation and Development (OECD), global oil prices have fallen and in some cases turned negative [1]. According to World Bank projections, global oil prices will remain depressed for the foreseeable future, though this will not result in a crisis [2].

The decrease in demand for electricity is one of the reasons for the drop in the price of oil and other energy commodities. According to the International Energy Agency (IEA), global demand for electricity is declining. When compared to the pre-pandemic period, China's demand for electricity fell by 11% [3]. Meanwhile, according to Indonesian electricity statistics [4], the overall decline in electricity demand has reached 6%. Specifically, in the Province of Yogyakarta, total demand for electricity increased by 5% during the pandemic period, owing to a 13% increase in demand for electricity in the household sector. However, there was a 3%, 5%, and 4% decrease in demand for electricity in the industrial, commercial, and social sectors, respectively.

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The economic recovery in Indonesia as a result of the Covid-19 pandemic is uncertain, and the impact on the energy sector could be long-lasting. The Indonesian government, on the other hand, has set ambitious targets for reducing annual value of carbon emissions from the energy sector, which are 10^6 Mt by 2050, in the national energy strategic plan [5]. The government, in particular, has set a target of 35% renewable energy in electricity supply by 2050 [6]. These objectives have not altered since the Covid-19 pandemic, and it appears that they will not change in the future. However, the approved generating capacity planning could be pushed back. Furthermore, a drop in energy commodity prices can have an impact on the amount of competition for renewable energy in the provision of electricity.

At the national level, lower energy commodity prices will lower the cost of oil and gas imports, allowing the budget to be transferred to other sectors, including the health sector in response to Covid-19. However, given the unpredictability of future oil and gas prices, this position raises concerns about the security of energy supplies. Furthermore, this issue may have an impact on the goal of incorporating renewable energy into the supply of electricity.

Governments and electricity providers can use quantitative models to evaluate how the costs and economic implications of various policies and expenditures may alter when the COVID-19 pandemic is finished. According to [7], an energy system is a collection of systems that obtain and utilize energy in a geographical or economic context. This definition is broadened to cover any physical object within a specified geographic area [8]. The approach used to analyze the operating principle of an energy system is part of the energy system analysis. Energy system analysis is a method for quantitatively analyzing future energy system capacity development from both technical and organizational perspectives [9]. The energy system model can be used to explain and analyze the complicated interactions between energy demand, energy supply, economic considerations, and environmental aspects [10]. Diverse energy system models have been constructed while considering various energy sectors, environmental challenges, energy supply security, and planning expenses. The technical components, data, skills required, technological specifications, required computations, and the scope and aims of the modeling all distinguish the energy models that have been produced.

Models from a variety of perspectives, including the top-down, bottom-up, and hybrid methods, are used to assess energy systems. The top-down approach employs an economic approach, with economic ideas underpinning the depiction of energy system interactions [11]. Bottom-up approaches are centered on technical issues and emphasis on energy sector technologies [12]. The hybrid strategy was created to integrate the benefits of top-down and bottom-up approaches while overcoming the shortcomings of the two preceding approaches. A hybrid method is utilized, with a strategy of integrating changed energy demand variables as endogenous variables [13], disaggregated input data into specific technologies [14], and other independent models used to accommodate current energy model input data [15].

There are various "ready-made" models available; nevertheless, existing energy system models are better suited to industrialized countries than emerging countries. Several studies in developing countries have used conventional energy system models to analyze specific sectors such as pollution mitigation in the household sector in Kenya [16], low carbon strategy development [17], and renewable energy implementation in the transportation sector [18] in Yogyakarta Province, Indonesia. An accounting framework method to energy system analysis is used to examine CO_2 mitigation measures in Yunnan Province, China [19] and in Thailand to analyze the implementation of renewable energy and energy efficiency strategies [20]. This model is also used to investigate low-carbon energy-supported development in poor countries [21].

The energy system model used for planning the supply of electricity employs an optimization model approach. The optimization model can be implemented using a single objective function approach [22] to minimize planning costs, or a multi objective function approach [23] that optimizes two objective functions, namely planning costs and environmental impacts. Multiple "ready-made" models can be used to optimize the incorporation of renewable energy into the electricity supply [24]. In general, the optimization model is applicable in both developed and developing nations. In most cases, the implementation of optimization models in developed nations involves the use of an objective function to maximize profit [25] or the development of a constraint function to meet revenue targets for power plant operators [26]. In developing countries, the objective function of the most optimization models is to minimize planning costs, which include investment costs and operational costs [27].

In previous studies, the impact of the COVID-19 pandemic on the planning of electricity supply has yet to be extensively examined. Implementing renewable energy in electricity supply is a government program that could be impacted by the diversion of resources to combat the Covid-19 pandemic. This article's contributions can be summed up as follows:

– comparative analysis of scenarios for the implementation of renewable energy in the supply of electrical energy, with a focus on post-covid-19 pandemic conditions; and
– quantitative analysis of the investment required to meet targets for implementing renewable energy in the supply of electrical energy.

In this case study, the energy-economy model is used in conjunction with the optimization model to analyze the long-term impact of the Covid-19 pandemic on plans to implement renewable energy in Yogyakarta Province's electricity supply. The analysis was conducted using a planning scenario approach that was as realistically prepared as possible in accordance with predetermined planning scenarios. Analysis includes the production of electricity to meet demand, the costs of planning, and the impact on the environment, which is represented by global warming potential (GWP).

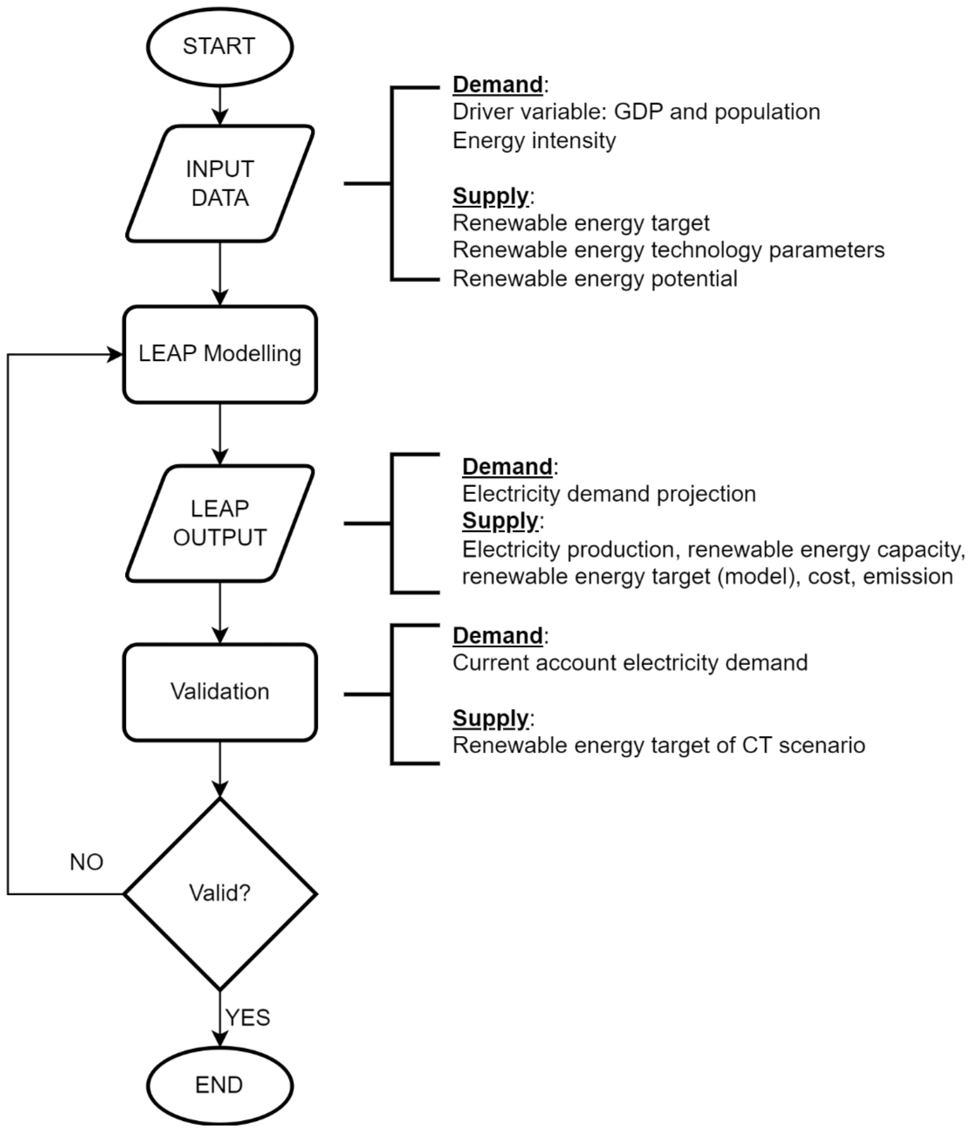

Figure 1: Analysis procedure based on LEAP.

The following section of this article will discuss research methods employing the energy-economy model (section 2), research data and data sources (section 3), research results and discussion (section 4), and conclusions (section 5).

2. Methods and scenarios

In this article, the analysis was conducted using the software Low Emission Analysis Platform (LEAP) and the Next Energy Modeling system for Optimization (NEMO) optimization model [28]. LEAP and NEMO have been utilized for policy analysis in the development of power systems [29] and scenario analysis for the implementation of renewable energy in power systems [30]. In addition to NEMO, the open-source energy modeling system (OSeMOSYS) can also be utilized for optimization in power system planning [31]. This research employs LEAP as an analytical tool due to its demonstrated efficacy and adaptability, as demonstrated in prior research. In energy system analysis, additional tools are available besides LEAP. Table 1 compares various tools.

In detail, the flow of modeling using LEAP is shown in the Figure 1. Demand and supply data comprise the data required to perform analysis using LEAP. Demographic, economic, and electricity intensity data comprise demand data. Supply-side data includes renewable energy targets, renewable energy technology parameters, and renewable energy potential. The LEAP model described in this article only considers one type of energy, namely electricity, from both the demand and supply sides. The LEAP model's output can also be analyzed from the demand and supply sides. The output from the demand side is the electricity demand projection. LEAP's output from the supply side consists of electricity produced by each process, renewable energy capacity built, costs, and emissions. Validation is performed on the LEAP model's output. On the demand side, the electricity demand in the base year (current account) must be identical to the demand from the data. On the supply side, renewable energy targets are one of the inputs that influence LEAP output. Minimum renewable energy targets are established, and validation is performed by comparing LEAP outputs to renewable energy target data.

2.1 LEAP model

Accounting framework-based energy system analysis is possible with LEAP. Additionally, LEAP includes an optimization model that can be used to analyze energy systems in the electricity generation industry. Various types of LEAP implementation for conducting energy system analysis, such as projections of energy demand and supply [39], the impact of energy efficiency activities on projections of energy demand [40], and economic evaluation of various scenarios of power generation technology in the supply of electrical energy [41] demonstrate the program's effectiveness. In addition, LEAP can be utilized to analyze climate change mitigation due to energy supply [42] and the role of bioenergy in reducing CO_2 emissions [43]. LEAP can be used to analyze energy substitution scenarios from conventional energy to new and renewable energy from a

Table 1: Comparison of tools for energy system analysis.

Name	Developer	Method	Scope
EnergyPLAN [32]	Aalborg University	Simulation/Optimization	Simulates and optimizes the operation of a national energy system for each hour of a given year.
HOMER Pro [33]	HOMER Energy LLC	Accounting/Optimization	Microgrid planning and optimization software
LEAP [34]	Stockholm Environment Institute	Accounting/Simulation/Optimization	Integrated Energy/Environment Analysis
MAED [35]	IAEA	Accounting	Energy Demand Modeling
PLEXOS [36]	Energy Exemplar	Optimization	Integrated Energy Planning
RETScreen [37]	NRCAN	Accounting	Energy production, life-cycle costs, and reductions in greenhouse gas emissions for numerous energy-efficient and renewable energy technologies
TIMES/MARKAL [38]	ETSAP	Optimization	Integrated Energy/Environment Analysis

socio-environmental perspective [44]. Using LEAP, the role of renewable energy in increasing energy independence has also been analyzed, in addition to its contribution to reducing emissions [45]. Moreover, LEAP can analyze the relationship between the water resource and the hydro system's electrical energy [46].

Additionally, LEAP is a flexible energy system analysis tool. A model structure that can be adapted to the requirements of the energy system being modeled demonstrates LEAP's adaptability. For instance, the analysis can be centered on the demand structure without regard to energy transformations. The demand structure can also be modified based on data availability, regardless of whether the model will be created with detailed or non-detailed data. The range of analyzed energy systems demonstrates LEAP's adaptability in the analysis of energy systems. Analysis of energy demand and production projections on a national scale with a case study in Pakistan [47] and analysis of emission reductions on a regional scale with a case study in Punjab, India [48] have been conducted using LEAP. Moreover, LEAP can be used to analyze sectoral energy systems, such as the role of solar collectors in reducing emissions in the industrial [49] and commercial [50] sectors. In the development of the green transportation sector, LEAP has also been implemented in economic and environmental analysis [51]. To combat climate change, LEAP can also be implemented at the household [52] and rural community [53] levels.

2.2 Energy demand analysis

Energy demand analysis in LEAP can be done using both end-use analysis and scenario analysis approaches. The energy demand (E_k^D), expressed in GWh, is calculated using

$$E_k^D = \sum_i \sum_j I_{i,j,k} \times A_{i,j,k} \tag{1}$$

where $A_{i,j,k}$ represents the level of activity for each sector i technology j, and fuel k, and $I_{i,j,k}$ represents the energy intensity (expressed in energy per unit of activity) for each sector i technology j, and fuel k. For each sector, the activity level ($A_{i,j,k}$) is expressed in activity units. The number of households represents activity in the household sector. Activity levels in the commercial, industrial, and public sectors are expressed in USD, which is the value of the gross regional domestic product (GDP). This article also considers electrification in the road transportation sector. The level of activity in the road transportation sector is measured in Passenger-Km and Ton-Km, respectively, for passenger and goods transportation.

2.3 Energy supply analysis

Energy supply analysis is a process that consists of an energy supply system and the optimization of the type of electricity generation technology. The amount of net energy consumption used in the energy transformation calculation is expressed as

$$E_l^T = \sum_m \sum_n E_{m,n}^P \times \frac{1}{f_{m,n,l}} \tag{2}$$

where E_l^T is the net energy consumption (in GWh), $E_{m,n}^P$ is the energy transformation result (in GWh), and $f_{m,n,l}$ is the efficiency. The indices m, n, and l respectively are indexes for types of secondary energy, types of electricity generation technology, and types of primary energy used for each process of electricity generation. For each process of generating electricity technology, apply

$$Input_P = \frac{Output_P}{Efficiency_P} \tag{3}$$

where output energy for each process p, $Output_P$, is the same as E_l^T in equation (2). While $Input_P$ is the energy input from the fuel used in every process of electricity generation technology. Whereas

$$Efficiency_P = 1 - Losses_P \tag{4}$$

applies to the process of transmission and distribution of electricity to the customer. In equation (3), the input is the fuel in each process of generating electricity p. Output is the amount of electricity produced by each process of generating electricity p.

In the analysis of electricity supply, the calculation of greenhouse gas (GHG) emissions is a calculation that must be carried out. GHG emissions (GHG_l), expressed in Tons of CO_2 Equivalent, produced for each process of generating electricity is expressed as

$$GHG_l = \sum_l \sum_m \sum_n E_{m,n}^P \times \frac{1}{f_{m,n,l}} \times F_{m,n,l}^{GHG} \tag{5}$$

where $F_{m,n,l}^{GHG}$ is a GHG emission factor.

The process of providing electricity is modeled using two main sources based on the location of the case study in this article, namely electricity imported from systems outside the province and electricity generated from the utilization of locally available renewable energy potential. The imported electricity comes from the Java-Madura-Bari (JAMALI) interconnection system, which uses coal, natural gas, and oil as fuel in the electricity generation technology. Meanwhile, the renewable energy potentials in Yogyakarta Province modeled in this article include solar, wind, bioenergy (including biomass and biogas), hydropower, and geothermal. In this article, optimization analysis is used to determine the optimal configuration in the supply of electricity by generating system variables such as power plant capacity to be built and primary energy needs.

2.4 Scenarios

The impact of Covid-19 on plans to implement renewable energy in the supply of electricity is analyzed using three scenarios. These scenarios describe immediate and long-term direct and indirect effects. The three scenarios are as follows:

- Constant target (CT): in this scenario, the predetermined targets do not change after the Covid-19 pandemic is over. The target set by the government for implementing renewable energy is the same as the target set in this article.
- Lower target (LT): The emergency situation of the Covid-19 pandemic resulted in a temporary shift in priorities, delaying the implementation of renewable energy in the supply of electricity. In this scenario, the government's targets are not met on time. As a result, the contribution of renewable energy to the supply of electricity is lower when compared to the CT scenario.
- Supply security (SS): this scenario is more optimistic than the CT scenario. In this scenario, the government prioritizes investment in order to increase energy independence by maximizing all existing renewable energy potentials and decreasing reliance on imported electricity.

The CT and LT scenarios are implemented in the LEAP software by changing the target renewable energy parameter. The SS scenario is based on optimization calculations to maximize the potential of existing renewable energy in the supply of electricity while disregarding the government's previously set targets.

The scenarios modeled in this article consist of 3 scenarios, namely constant target (CT), lower target (LT), and supply security (SS) scenarios. The CT scenario is based on the renewable energy implementation plan published by MEMR [6]. The LT scenario has the same target size but is 5 years slower than the CT scenario. This is an indicator of the impact of the budget diversion that occurred after the Covid-19 pandemic. The SS scenario is a more optimistic scenario when compared to the CT scenario where the security of electricity supply is prioritized. The SS scenario is implemented through optimization calculations to maximize every renewable energy potential in Yogyakarta Province so as to reduce dependence on imported electricity.

Table 2 contains a detailed description of each scenario. On the energy supply side, these three scenarios are implemented. Furthermore, the electrification target in the road transport sector is the same for all three scenarios. As a result, these three scenarios have no bearing on energy demand calculations.

3. Data and data sources

This section discusses the data required for the research as well as the sources used to obtain it. The data used in this article includes demographics, economics, electricity demand, renewable energy potential in Yogyakarta Province, and technical, economic, and environmental characteristics of each generation technology.

3.1 Demographic and economic conditions

Demographic data required for LEAP modeling include population, population growth, number of households, and household size. Table 3 displays the data for 2020 According to [6], the average population growth rate until 2050 is 0.7% per year. Figure 2 depicts the projected population growth and number of households based on this average growth rate and assuming the same household size.

Table 2: Scenario description for renewable energy target variables.

Scenarios	Renewable Energy Target (%)				
	2030	2035	2040	2045	2050
CT	33.33	36.6	37.4	38.7	40
LT	20	33.33	36.6	37.4	38.7
SS	Optimized based on maximum potential				

Table 3: Demographic data of Yogyakarta Province [54].

Demography	Data in 2020	Units
Population	3,892,640	People
Population Growth	1.30	%
Household	1,184,970	Household
Household size	3.29	People

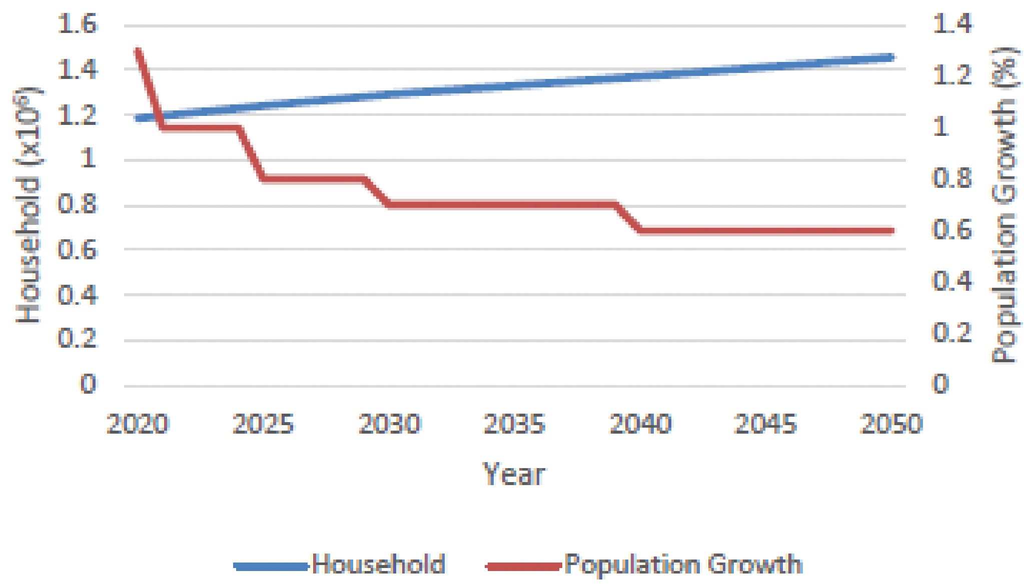

Figure 2: Household number and population growth in Yogyakarta Province along the projection period.

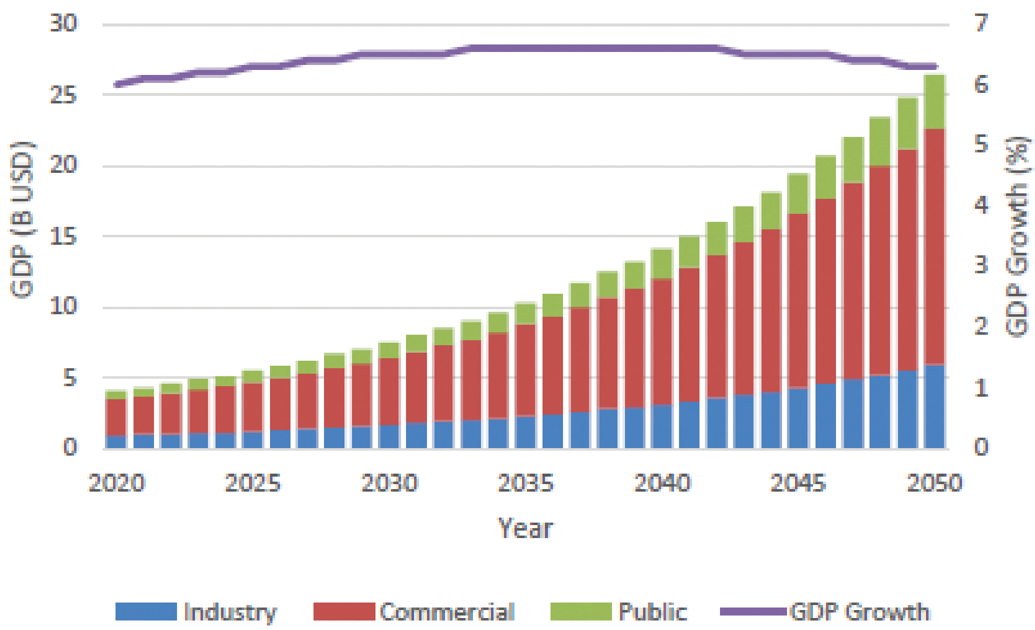

Figure 3: GDP and GDP growth in Yogyakarta Province along the projection period.

Table 4: Sectoral GDP of Yogyakarta Province [55].

Sector	GDP (M USD)
Industry	901.68
Commercial	2,570.61
Public	591.27

In addition to demographic data, LEAP requires economic data in the form of GDP values and GDP growth. Based on data published by Statistics Indonesia, the GDP values and for each sector in 2020 are shown in Table 4. Based on the projected GDP growth [6], the GDP value for each sector and the GDP growth are shown in Figure 3.

Table 5: Road transportation sector activity in Yogyakarta Province [56].

Transportation Mode	Number of Vehicle (unit)	Operational (%)	Load Factor	Distance (Km per year)
Passenger Car	414,810	40	1.8 (Passenger per vehicle)	20,100
Bus	53,720	10	42 (Passenger per vehicle)	31,000
Truck	170,910	10	8.25 (Ton per vehicle)	31,000
Motorcycle	3,677,070	49	1.3 (Passenger per vehicle)	8,000

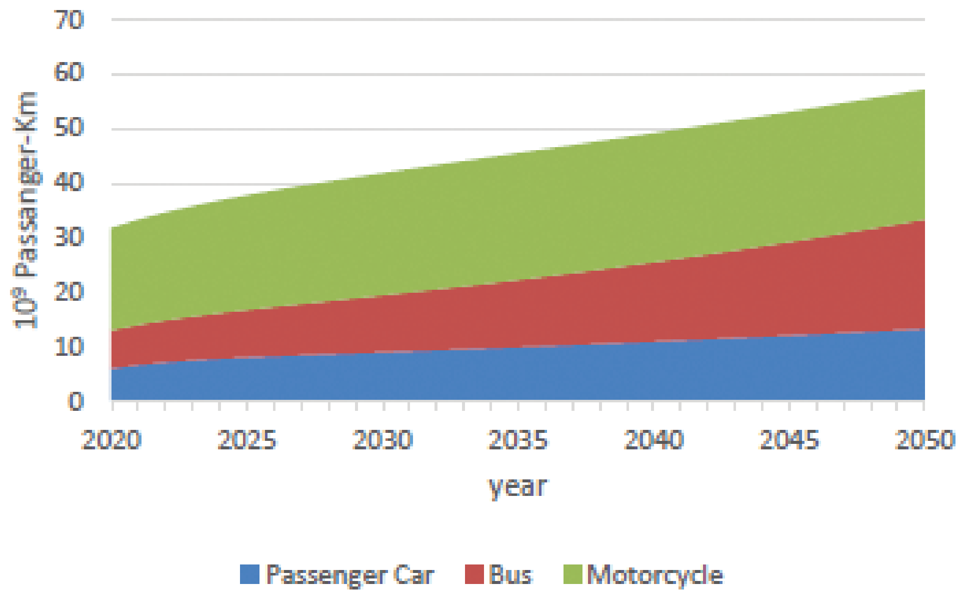

Figure 4: Passenger road transportation activity in Yogyakarta Province along the projection period.

Table 6: The intensity of the road transportation sector in Yogyakarta Province [56].

Transportation Mode	Energy Intensity	Unit
Passenger Car	1.71	MJ per passenger-Km
Bus	0.15	MJ per passenger-Km
Truck	0.91	MJ per ton-Km
Motorcycle	0.75	MJ per passenger-Km

3.2 Road transportation conditions

Data on the activity and intensity of the road transport sector were obtained from a survey conducted by the Indonesian Ministry of Energy and Mineral Resources (MEMR). The activity and intensity of the transportation sector for Yogyakarta Province are shown in Table 5 and Table 6 respectively. The growth in road transport activity is projected to have the same growth as GDP growth. The projected results of road transportation activities are shown in Figure 4 dan Figure 5. Currently, the energy demand in the road transportation sector is met by using primary energy derived from oil, namely gasoline and diesel. Based on [6], 1.6% of the primary energy of petroleum is projected to be converted into electricity. This target is expected to be achieved in 2050.

3.3 Electrical power system current conditions

Yogyakarta Province's electricity system is part of the interconnection system that connects the islands of Java, Madura, and Bali (JAMALI system). Because there are no installed power plants in Yogyakarta, all of the province's electricity needs are currently met by importing electricity from outside the province. Currently, the price of electricity imported from the JAMALI system is 8.7 US cents [57]. Table 7 shows the number of customers and demand for electricity in 2020, based on data from the National Electricity Company (PLN) , with a transmission and distribution line loss of 9.41%. The JAMALI system's electricity production is still dominated by fossil fuels, specifically 50% coal and 26% natural gas. Both fuel types contribute to carbon dioxide

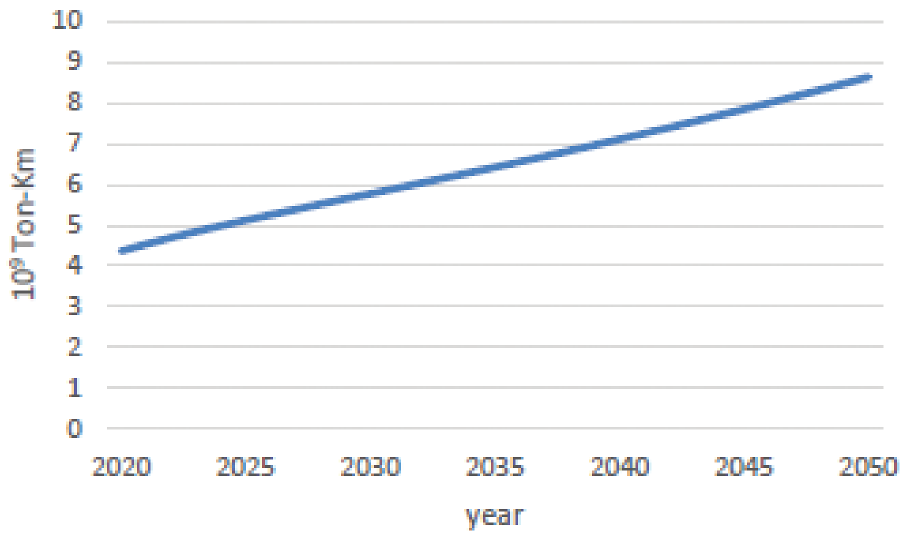

Figure 5: Goods road transportation activity in Yogyakarta Province along the projection period.

Table 7: Number of customers and demand for electricity in Yogyakarta Province [57].

Sector	Number of customers	Connected Capacity (MVA)	Electricity Demand (GWh)
Household	1,202,160	1,192.66	1,703.52
Industry	755	122.87	244.51
Commercial	62,752	488.94	697.83
Public	45,210	266.58	366.59

Table 8: Renewable energy potential in Yogyakarta Province [6].

Renewable Energy	Technical Potential (MW)
Geothermal	10
Hydro	5
Biomass	183
Biogas	41
Solar	996
Wind	1,079

emissions at an external cost of 50 USD per ton [58]. As shown in Table 7, the road transportation sector still does not use electricity. Despite the fact that all electricity needs are met by importing from outside the province, Yogyakarta has renewable energy potentials that can be optimized for power generation. Table 8 depicts the renewable energy potentials in Yogyakarta Province.

3.4 System component characteristic

LEAP modeling parameters for each type of electricity generation technology include technical, economic, and environmental parameters. The technical parameters of a power plant include efficiency expressed in heat rate, planned outage rate (POR), and forced outage rate (FOR). POR and FOR are used to calculate a power plant's maximum availability over a year. Maximum availability is specified by

$$A_g^{max} = 1 - \left(POR_g + FOR_g\right) \quad (6)$$

where A_g^{max} is the maximum availability for each type of generator g.

Capital costs, variable operation and maintenance (O&M) costs, and fixed O&M costs are the economic characteristics of each power plant that uses renewable energy sources. Meanwhile, environmental characteristics are parameters that express the amount of greenhouse gas emissions produced by each type of power plant [59]. Environmental criteria are applied to conventional power plants located outside of Yogyakarta Province.

In detail, the technical and economic characteristics for power generation technology with renewable energy sources are shown in Table 9 and Table 10 respectively. For energy storage technology, the battery is the type of

Table 9: Technical parameters of renewable energy power plant [60].

Renewable Energy Technology	Heat Rate (kWh/kWh)	POR (%)	FOR (%)
Geothermal	1	2.41	0.75
Hydro	1	1.9	5
Biomass	4.10	7.6	9
Biogas	3.95	7.6	9
Solar	1	2	0
Wind	1	0.6	5

Table 10: Economic parameters of renewable energy power plant [60].

Renewable Energy Technology	Capital Cost (USD/kW)	Variable O&M (USD/MWh)	Fixed O&M (USD/kW-yr)
Geothermal	5,940	31	31
Hydro	3,500	6	15
Biomass	3,830	15	95
Biogas	3,830	15	95
Solar	2,280	2,280	43
Wind	1,980	1,980	60

Table 11: Technical and economic parameter of battery [60].

Storage Technology	Round-Trip Efficiency (%)	POR (%)	FOR (%)
Battery	75	0.55	2
	Capital Cost (USD/kW)	Variable O&M (USD/MWh)	Fixed O&M (USD/kW-yr)
Battery	3,690	59	25.2

technology used in this article. The technical and economic characteristics for the battery are shown in Table 11. The discount rate influences the cost of investment in power generation capacity planning. This article uses a discount rate of 5%.

4. Result and discussion

Based on the data described in section 3, the simulation with the LEAP model is run with 2020 as the base year and 2050 as the final year. The selected simulation's end year has been adjusted in accordance with the energy planning document published by Indonesia's Ministry of Energy and Mineral Resources (MEMR) [6]. The analysis is carried out in the form of projected electricity demand for each sector, including the road transportation sector, electricity supply for each scenario, additional renewable energy generation capacity for each scenario, and an analysis of costs and emissions as a result of the development of renewable energy in the supply of electricity in Yogyakarta Province [6].

4.1 Energy demand projection

The implementation of the three scenarios has no effect on electricity demand, as explained in section 2.4. Based on the parameters that have been determined in the Data and data sources section, the demand for electricity until 2050 for each activity sector is shown in Figure 6. According to Figure 6, the average growth rate of energy demand in the industrial, commercial, and public sectors is 6.40% per year over the projection period. GDP growth influences the growth of electricity demand in these three sectors. Demand for electricity in the household sector has increased by 1.30% per year on average between 2020 and 2050, which is influenced by the increase in the number of households. Meanwhile, energy demand in the transportation sector has the highest average annual growth rate, at 17.50%.

With these growth values, the demand for electricity for the industrial, commercial, and public sectors in 2050 is 1.6 TWh, 4.5 TWh and 2.4 TWh respectively. In 2050, the demand for electricity for the household sector will reach 2.6 TWh. The transportation sector is projected to have electricity demand starting in 2026 with

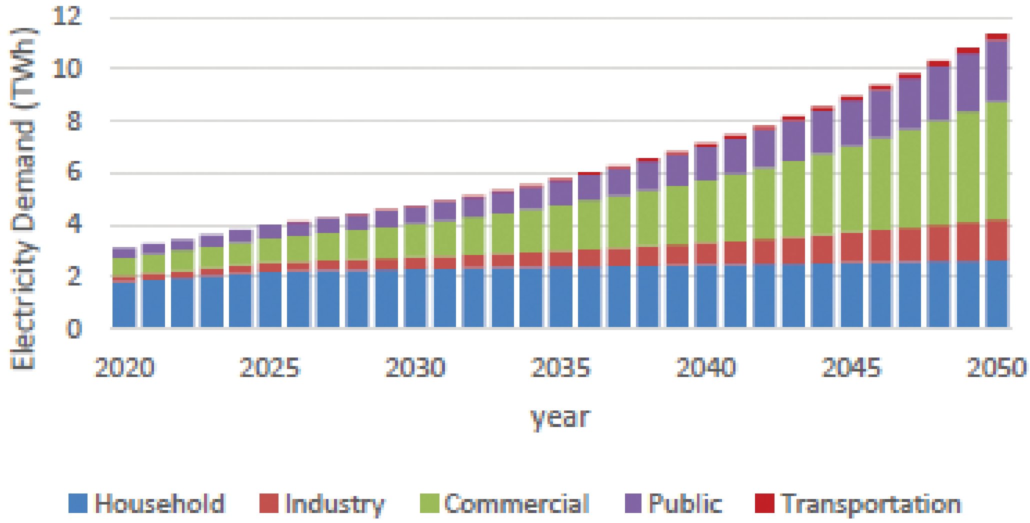

Figure 6: Electricity demand by sector in Yogyakarta Province along the projection period.

electricity demand in 2050 reaching 0.2 TWh. Overall, Yogyakarta Province's electricity demand in 2050 is 11.4 TWh with an average growth of 4.40% per year.

4.2 Energy supply analysis

To meet the demand for electricity as described in section 4.1 and assuming the target of implementing renewable energy in Table 2, the production of electricity required for each scenario is shown in Figure 7. Based on the CT scenario (Figure 7 (a)), renewable energy sources used to produce electricity are wind turbines, hydro, and biomass. From the optimization results, wind turbines will start to produce electricity from 2025 to 2050. And hydro-fuel power plants will start to produce electricity from 2028 until the end of the projection period. Meanwhile, biomass power plants will only produce electricity in 2050. In 2050, the electricity generated by wind turbines, hydro-fueled power plants, and biomass will be 4.3 TWh, 0.02 TWh, and 0.1 TWh respectively. These results indicate that, based on the CT scenario, hydro turbines are infeasible because their proportion is so small in comparison to other technologies. When compared with the total produced electricity, these three types of renewable energy produce 39% of electricity. It can also be seen that electricity that must be imported from outside Yogyakarta Province is still dominant, namely 65% of the total electricity production. There are variances between the derived results and the input data regarding the renewable target energy for the CT scenario. This difference is depicted in Figure 8, where the difference obtained will diminish throughout the projection. In 2050, the gap between model results and data will be only 0.25 percent.

Based on the LT scenario, the pattern of electricity production is different from that produced by the CT scenario. In Figure 7 (b), it can be seen that wind and hydro turbines are renewable energy power plants that contribute to the supply of electricity. Wind turbine and hydro power plants will produce electricity in 2050 of 3.8 TWh and 0.02 TWh respectively. As with the CT scenario, planning based on the LT scenario does not permit the use of hydro turbines. Overall, these two renewable energy plants contribute 31% of the total produced electricity. From the optimization results based on the LT scenario, dependence on imports of electricity is higher when compared to the CT scenario. Electricity that must be imported to meet demand in 2050 is 70% of all electricity that must be supplied.

Electricity production based on the SS scenario, where all renewable energy potentials are optimized, is shown in Figure 7 (c). From the optimization results based on the SS scenario, all potential renewable energy in Yogyakarta Province can be optimized to meet the demand for electricity. In 2050, renewable energy can contribute 65% in the production of electricity to meet demand. In other words, dependence on imported electricity in 2050 is only 35%, which is the lowest value when compared to the two previous scenarios. It can also be seen that the SS scenario produces the highest energy independence in 2034 where the electricity that

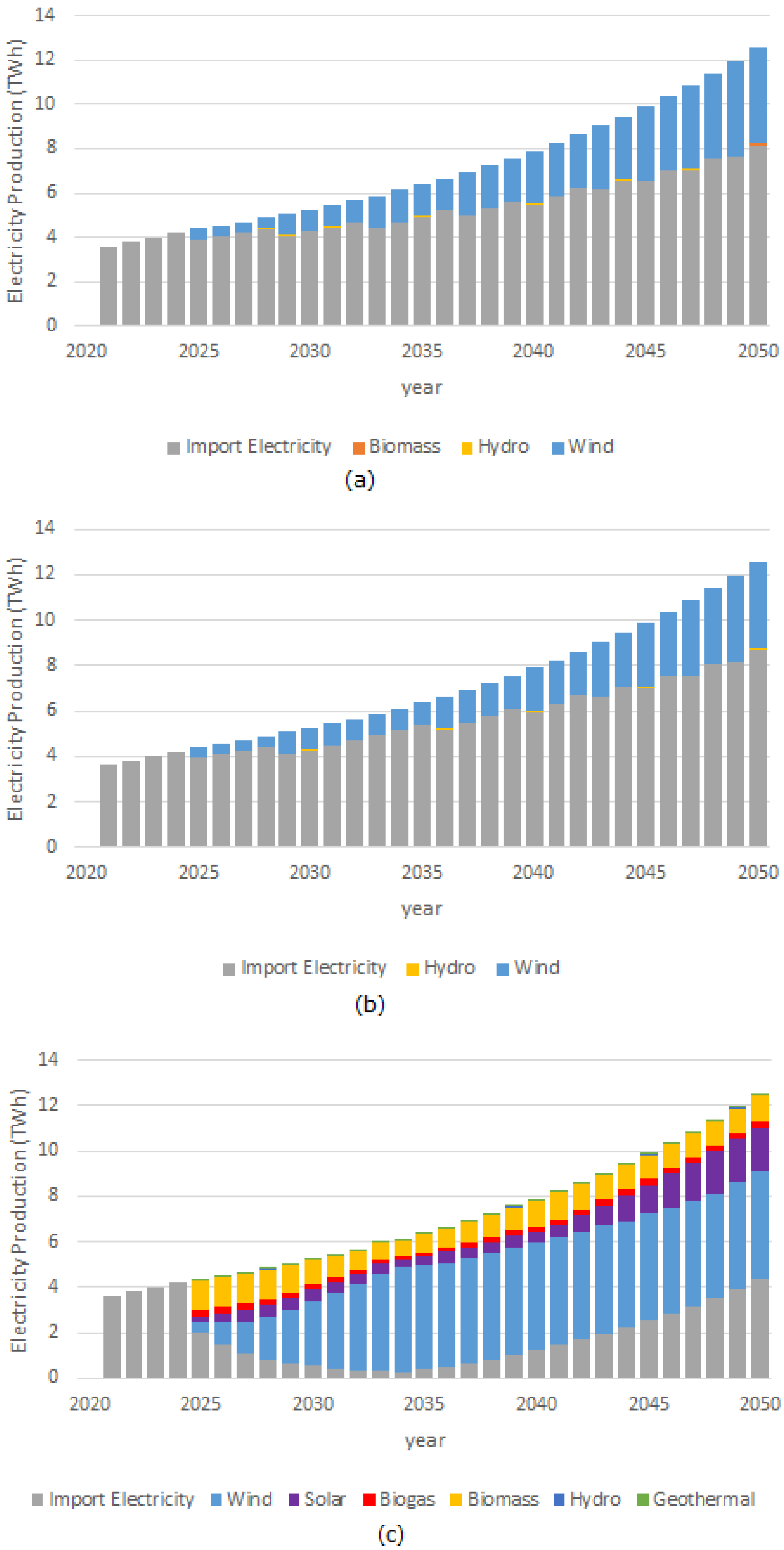

Figure 7: Electricity production for (a) CT scenario, (b) LT scenario, and (c) SS scenario.

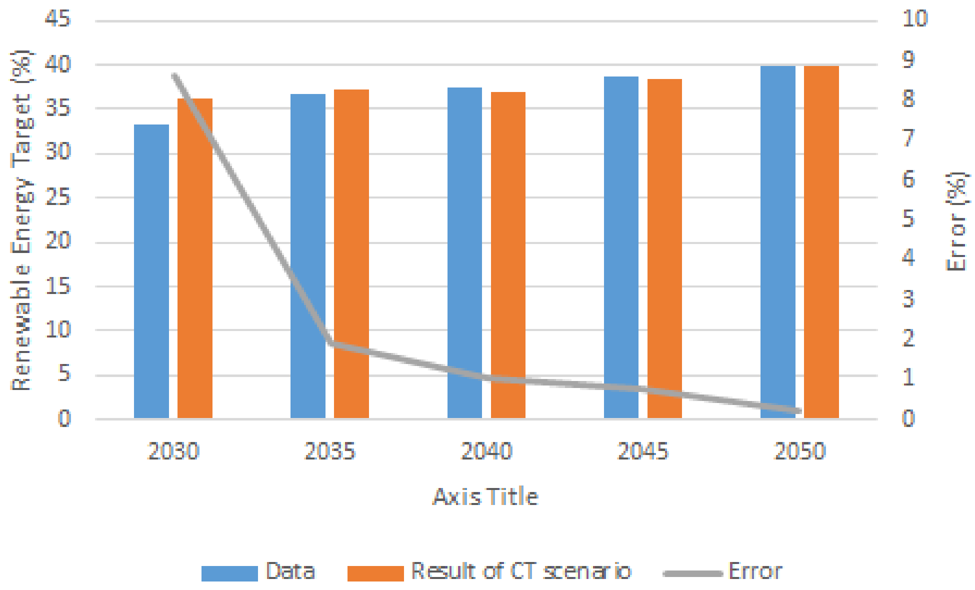

Figure 8. Comparison of renewable energy target between data and result of CT scenario.

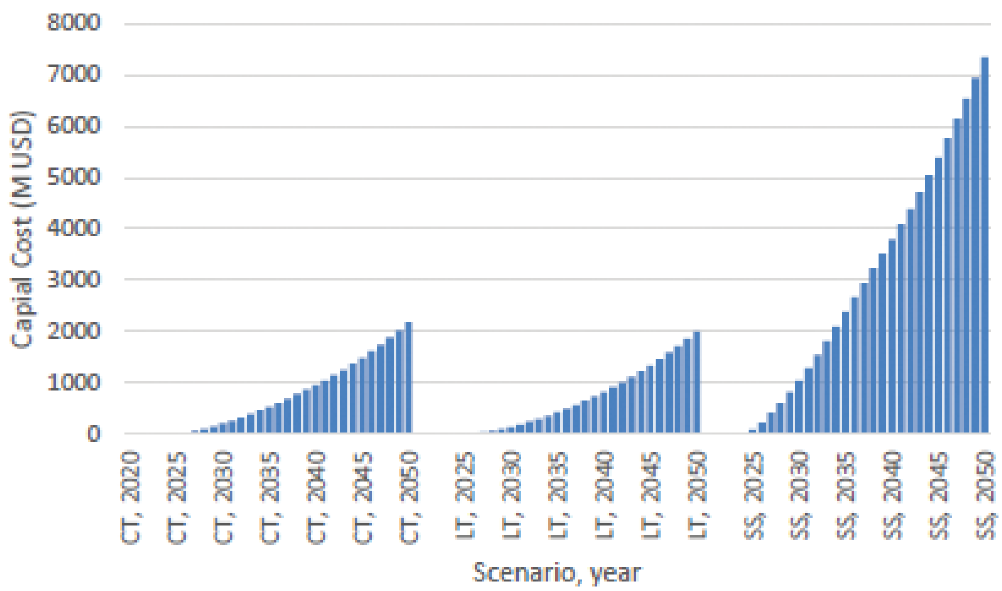

Figure 9: Comparison of cumulative capital cost for each scenario.

must be imported is only 5% of the total electricity that must be supplied.

4.3 Cost and environment analysis

In terms of planning costs, the SS scenario is significantly more expensive than the CT and LT scenarios. Figure 9 depicts the total capital cost for each scenario. The SS scenario results in a total capital cost of 7.3 B USD in 2050. While the CT and LT scenarios have cumulative capacity costs of 2.2 B USD and 2.0 B USD, respectively. The construction of power plants using renewable energy sources results in capital costs.

The addition of power generation capacity with renewable energy technology is shown in Figure 10. Figure 10 (a) depicts the results of adding power plant capacity based on the CT scenario, which include three types of renewable energy power plants: wind turbines, hydro, and biomass. As can be seen, the CT scenario

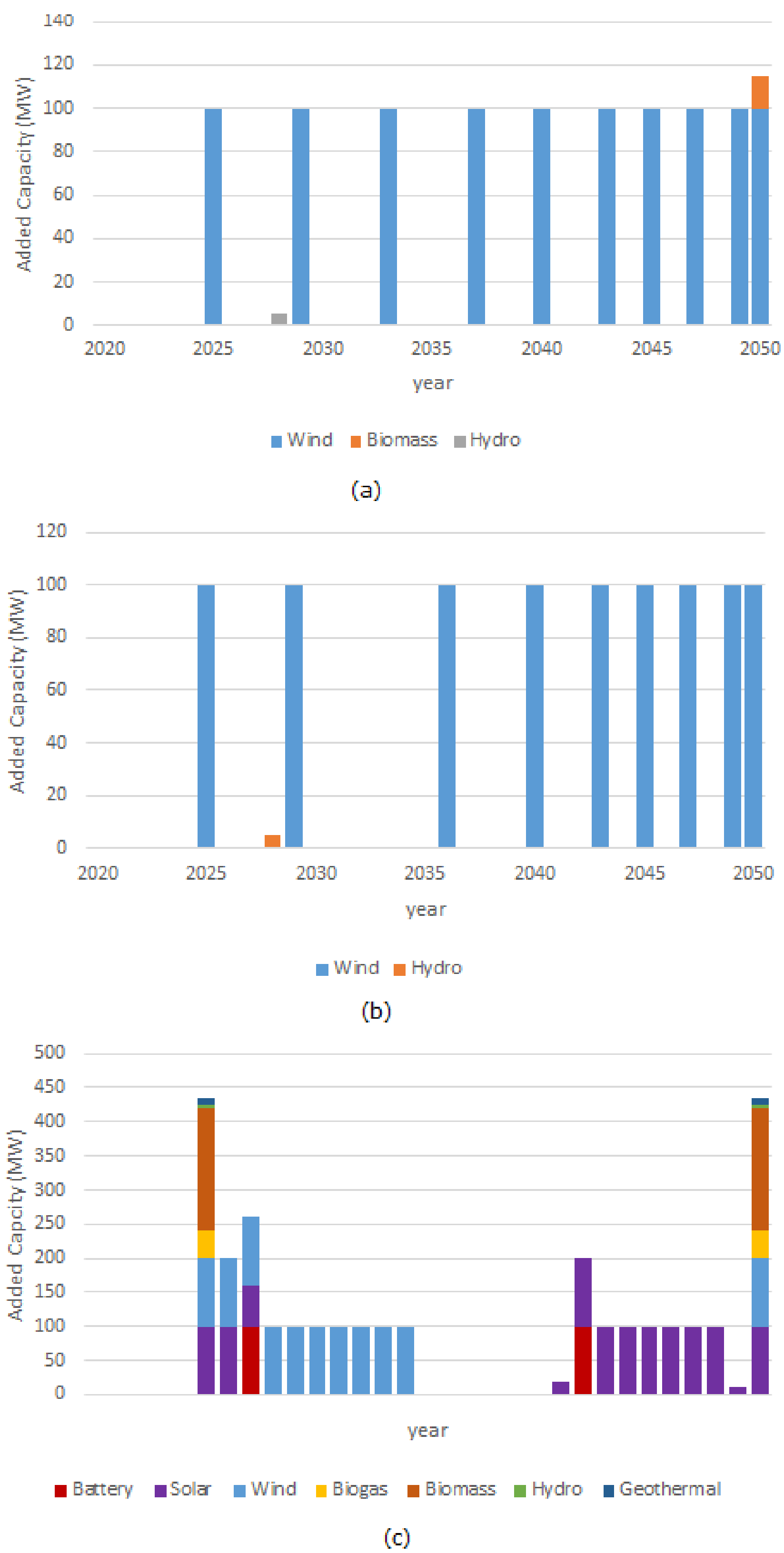

Figure 10: Capacity addition for (a) CT scenario, (b) LT scenario, and (c) SS scenario.

results in increased capacity for wind turbines, hydro, and biomass to their full potential. The capacity of wind turbines built in 2048 is 1,000 MW. Meanwhile, a hydropower plant with a maximum capacity of 5 MW will be built in 2028. The renewable energy power plant capacity that must be built based on the calculation results with the LT scenario, on the other hand, is only wind turbine and hydro, as shown in Figure 10 (b). The maximum capacity for both types of renewable energy is built in 2028 for hydro and 2048 for wind turbines, as in the CT scenario.

Figure 10 (c) shows the results of calculating annual capacity additions based on the SS scenario. As can be seen, the SS scenario necessitates the construction of power generation capacity for all existing renewable energy potentials. In 2025, biogas, biomass, hydro, and geothermal power plants will reach their full potential. Meanwhile, wind turbines and solar power plants will be constructed in stages beginning in 2025. Wind turbines will reach their peak capacity in 2034, while solar power plants will peak in 2049. The SS scenario's renewable energy system also necessitates the construction of energy storage, specifically batteries, with a capacity of 100 MW in 2027.

In terms of impact on the environment, the global warming potential (GWP) emissions produced by each scenario are shown in Figure 11. Figure 11 depicts the total GWP caused by CO_2, CH_4, and NO_X emissions. In contrast to the capital cost calculation results, the SS scenario has the lowest global warming potential of the three scenarios. In 2050, the SS scenario's cumulative GWP potential is 14.4 Mt CO_2 Equivalent, or 65% less than the CT scenario's.

The cumulative costs and benefits relative to the CT scenario can then be calculated based on an analysis of planning costs and environmental impacts. Figure 12The cumulative costs and benefits from 2020 to 2050 are depicted in Figure 10. Compared to the CT scenario, the LT scenario has a power generation planning cost reduction of 0.1 billion US dollars. However, the cost of importing electricity is 24 M USD more than what the CT scenario requires. Similarly, the LT scenario generates externality costs that are 31 M USD more expensive than the CT scenario. When the SS scenario was contrasted to the CT scenario, the opposite occurred. The SS scenario generates planning costs that are 2.3 B USD more than the CT scenario. However, the costs of electricity imports and externalities under the SS scenario are significantly lower than under the CT scenario, at 365 M USD and 465 M USD, respectively, compared to the CT scenario.

When compared to the CT scenario, the total net present value (NPV) generated by the LT scenario is 56 M USD lower. Meanwhile, when compared to the CT scenario, the SS scenario has a higher NPV value of 1.5 B USD. When it comes to GHG savings, the LT scenario produces a lower value than the CT scenario, which is 1.2 Mt CO_2 Equivalent. When compared to the CT scenario, the SS scenario produces much greater GHG savings, namely 22 Mt CO_2 Equivalent. However, the

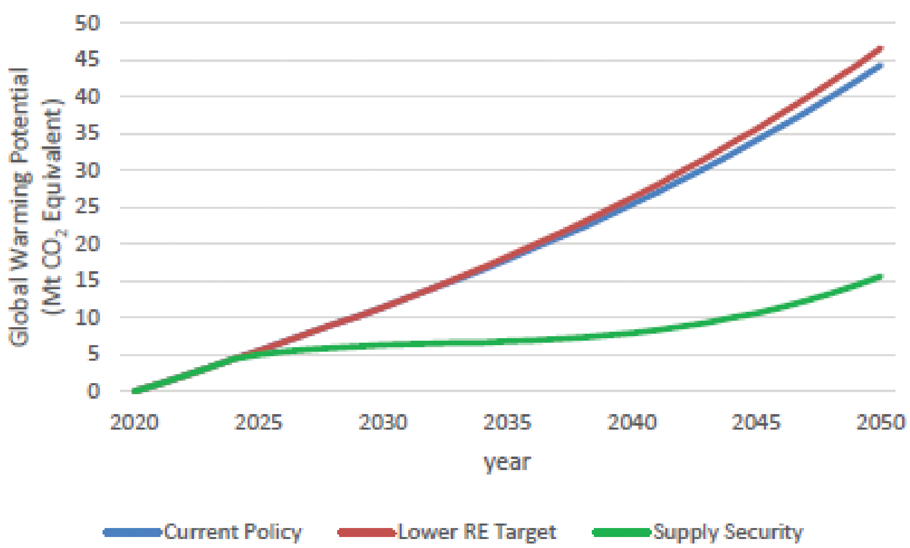

Figure 11: Cumulative global warming potential for each scenario.

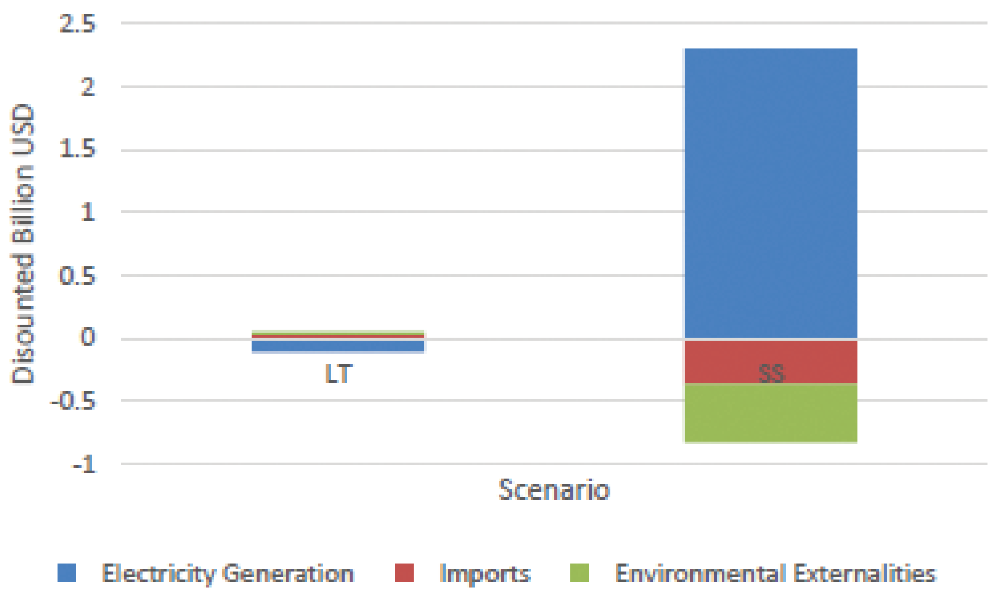

Figure 12: Cumulative cost and benefit of LT and SS scenario relative to CT scenario.

cost of avoided GHGs required to achieve the value of GHG savings by the SS scenario is 66 USD/Ton CO_2 Equivalent.

According to the analysis, the situation following the Covid-19 pandemic has had a significant impact on plans to implement renewable energy in the supply of electricity. When compared to the existing plans [6], two scenarios, the LT scenario and the SS scenario, produce different plans. In situations where the government's budget is still focused on post-covid-19 recovery projects, the LT scenario is very feasible to implement. And achieving the SS scenario is a very optimistic condition. The SS scenario is doable with a significant increase in budget.

5. Conclusion

An analysis of the post-pandemic situation's impact on the implementation of renewable energy in the supply of electricity has been conducted. The findings of this analysis indicate that the Covid-19 pandemic will have an impact on predetermined plans to achieve renewable energy targets in the supply of electricity, particularly in Yogyakarta Province. With delays in meeting the renewable energy implementation target described by the LT scenario, Yogyakarta Province's electricity supply is more reliant on imports than in the CT scenario. Furthermore, when compared to the CT scenario, the LT scenario produces higher total GHG emissions while incurring lower planning costs.

The analysis results based on the SS scenario show that by optimizing every existing renewable energy potential, Yogyakarta Province can achieve a higher level of energy independence. Nonetheless, this level of energy independence will decline once each potential renewable energy source has reached its maximum capacity. Furthermore, when compared to the other two scenarios, the SS scenario has the highest planning costs but the lowest GWP emissions.

Further analysis can be performed by incorporating demand side management into the planning of electricity provision while accounting for post-covid-19 pandemic situation. Further analysis can be carried out by observing changes to the discount rate, the price of imported electricity, and specific investment in renewable energy. Furthermore, optimization models can be developed to accommodate uncertainties, particularly those associated with the prices of traditional energy commodities such as oil and gas.

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