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Optimizing the Development of Power Generation to Increase the Utilization of Renewable Energy Sources

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Abstract. The electric power system is critical to supporting the economic growth of a country. On the other hand, the growing concern about the environment in recent years has pushed many countries to create strategies to minimize greenhouse gas emissions by increasing the proportion of new and renewable energy (NRE) sources. In Indonesia, the Java-Bali power grid is the most extensive electricity system, with a demand of 177,692.43 GWh with a peak load of 40,059.74 MW in 2019. However, the energy mix in Java-Bali is dominated by coal at 70%, followed by natural gas at 21.22%, renewable energy at 7.71%, and fuel at 0.14%. Therefore, there is an urgent need to increase the use of NRE sources in fulfilling the electrical energy demand, with the government setting a renewable energy utilization target of 23% in 2025 and 31% in 2050. This study aims to create a power-generating capacity development planning scenario with the best use of NRE sources at the lowest cost, to support the Indonesian policymakers in obtaining those targets. The Balmoral model with General Algebraic Modeling System (GAMS) programming was used to optimize the planning model for the power generating capacity. The results show that the development planning scenario with a total additional generating capacity of 15,035 MW is the scenario with the most optimal utilization of NRE sources and the lowest cost, with an estimated total investment cost of IDR 901 trillion. Furthermore, this scenario can increase the composition of renewable energy in the Java-Bali system to 16.95% in the next ten years.

Keywords: Energy transition; Gas emissions; Power generation; Renewable energy

1. Introduction

The electricity sector promotes economic growth (Elfani, 2011). As one of the main components in supporting the process of producing goods and services, reliable electrical energy positively impacts the growth of a country's gross domestic product (GDP) figure (Akinbulire et al., 2014). On the other hand, population and economic expansion, rising social status, and technological advances have increased the demand for electrical energy, which must be provided effectively, reliably, and sustainably (Babatunde et al., 2019; Günther, 2018).

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However, the electricity sector is known as harmful to the environment, particularly those using fossil fuels. The growing environmental concerns have prompted many economies to make the energy transition to reduce their greenhouse gas emissions as one of the goals to accelerate global energy sustainably and equitably, focusing on three main pillars: access, technology, and financing (Setiawan & Asvial, 2016). Increasing the portion of new and renewable energy (NRE) sources is one of the strategies that can be done to address those environmental issues (Luz et al., 2018). Besides, the availability of fossil fuels in the future also needs to be anticipated; hence, renewable energy must be considered in power capacity enlargement planning (Muthahhari et al., 2019).

Indonesia's composition of new renewable energy (NRE) sources is targeted to reach in 2023 and 31% in 2050; however, as of 2021, it has only reached 11.5%. Therefore, this research aims to develop planning scenarios for power generation progression with the optimal utilization of NRE sources, particularly for the Java-Bali grid, the backbone of Indonesia's electricity supply. The development of power generators using NRE sources needs to be carried out at the most efficient cost by considering the installed generating capacity, projected energy needs, potential primary energy sources, energy mix policies, technical data for generators, and investment costs for generators (Khan et al., 2014; Sima et al., 2019). This study is expected to contribute to developing national public policies and regulations on optimizing the expansion of NRE infrastructure in Indonesia.

2. Methods

The optimum maturity of electricity infrastructure and power generators is pursued with the principle of the least cost of electricity supply while emphasizing the provision of adequate power to consumers and the level of network dependability. The least cost was determined using the development planning model of generating capacity. The optimization of the development planning model for the power generating capacity in this study was carried out using the Balmoral model with General Algebraic Modeling System (GAMS) programming, the structure of which can be seen in Figure 1. Balmoral is a widely utilized energy sector analysis model that focuses on energy systems' complex optimization problems. GAMS models are stated in concise algebraic statements that can be analyzed to evaluate whether the model created is as expected (Ćalasan et al., 2021).

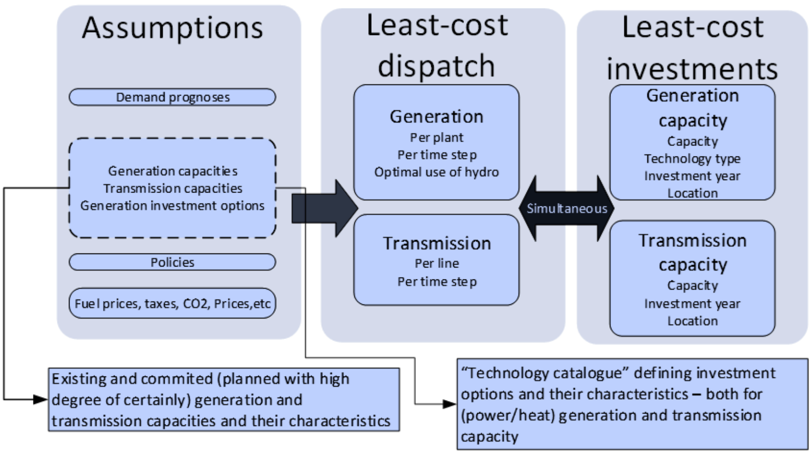

Figure 1 Balmoral Model Structure

This study was conducted in two stages. A literature study was carried out in the first stage to obtain the variable data needed as the model input. The influencing factors for the enlargement planning of power plants consist of the installed generating capacity (X1), projection of electrical energy demand (X2), potential primary energy source (X3), energy mix policy (X4), generator technical data generation (X5), technology investment costs (X6), price of thermal generation as the primary energy (X7) (Babatunde et al., 2019; Muthahhari et al., 2019; Sima et al., 2019; Moreira et al., 2017; Winarno et al., 2017; Khan et al., 2014). The data on these influencing factors were collected from official documents, such as the General Plan for the Provision of Electricity (RUPTL), the General Plan for National Energy (RUEN), and General Plan for National Electricity (RUKN).

In the second stage, a case study of the model was conducted using three scenarios, as seen in Table 1. In the first scenario, all parameter data was based on the power plant capacity development plan developed by PT PLN, a state electricity company. On the other hand, only capacity data for power plant projects already underway or under construction are considered in the second scenario. At the same time, the model optimized the remaining investment for the need for power plant capacity improvement. Moreover, the third scenario was built on the existing generating capacity with all ventures for generating capacity development requirements optimized by the model.

Table 1 Optimization model scenarios

No.	Scenario	Information
1	Business as Usual	Existing capacity + project plan data for additional generators
2	Ongoing project optimization	Existing capacity + ongoing projects + optimization
3	Overall optimization	Existing capacity + optimization

A comparative method was then used in analyzing the case study, which compared the results of each scenario to get a power plant development plan with the most efficient use of renewable energy or the lowest cost. Expert judgment was then used in the validation process (Berawi et al., 2021). The presented values can determine whether the planning scenario for power plant development utilizing the suggested renewable energy is practical and can be realized.

3. Results and Discussion

3.1. Influencing Factors for the Development Planning of Power Plants

3.1.1. Installed Generating Capacity (X1)

The Java-Bali electricity system is divided into five areas: DKI Jakarta & Banten, West Java, Central Java & DIY, East Java, and Bali. Based on the data from PT PLN collected at the beginning of this study, each area has a generating capability of 11,983 MW, 7,610 MW, 7,192 MW, 9,214 MW, and 939 MW as of 2019, respectively, totaling up to 36,933 MW. The installed generators in the Java-Bali system in 2019 were composed of several types of primary energy, which include 372 MW of fuel energy plants (1.01%) and 36,561 of non-fuel energy plants (98.99%), comprising 21,450 MW of coal (58.08%), 11,375 MW of natural gas (30.80%), 2,552 MW of hydropower (6.91%), and 1,184 MW of geothermal (3.21%).

3.1.2. Projection of Electrical Energy Demand (X2)

The projections of electrical energy demand were obtained using historical data and considering several indicators, such as sales of electrical energy, connected power, number of customers, economic growth, population, and electricity tariffs. Economic growth, population, and electricity tariffs are indicators that have a strong correlation with an increase or decrease in electricity consumption. In this case, the economic growth projection data uses the high scenario economic growth projection figures from the Indonesian Ministry of National Development Planning/Bappenas, the inflation rate from the National Electricity General Plan 2015-2045, and population growth and population projection data from the Indonesian Population Projection book (Bappenas et al., 2018). On the other hand, the assumption of the number of people per household refers to data from Indonesia's Central Statistics Agency (BPS).

The electricity sales in the Java-Bali power system projected using these assumptions were estimated to reach 272 TWh, indicating an average growth of 4.28% over the next ten years. The electrical energy demands in DKI Jakarta & Banten provinces were projected to grow by an average of about 3.7% and 3.2% per year in the next ten years, respectively. Meanwhile, the demands for electrical energy in West Java, Central Java, and DIY provinces were projected to grow by an average of about 4.6%, 5.2%, and 4.0% per year in the next ten years, respectively. Moreover, the electrical energy demands in East Java and Bali provinces were projected to grow by around 4.4% and 6.0% per year in the next ten years, respectively.

3.1.3. Potential Primary Energy Source (X3)

Power plant development planning and generator location selection are carried out by considering the availability of local primary energy sources, proximity to load centers, the principle of regional balance and the desired topology of the transmission network, constraints on the transmission system, and technical, environmental, and social constraints stated in Electricity Supply Business Plan (RUPTL 2019–2028). In areas with considerable coal potential, the prioritized power plant type to be developed is a mine-mouth steam power plant. It is also planned for areas with immense gas potential by creating gas-fired generators around the wellhead.

The potential renewable energy plants can be developed to fulfill the electricity demand if it has met the requirements from the local electric power system's supply-demand balance, feasibility study, and grid study. Furthermore, it can finance expansion at a price that follows applicable regulations. Data on potential primary energy sources for Java – Bali are presented in Table 2 below.

Table 2 Data on potential primary energy sources for Java–Bali

	Coal	Gas	Oil	Geothermal	Hydro	CBM	Mini hydro & Micro hydro	Bioenergy	Solar	Wind	Ocean Current
	(Million Ton)	(BCF)	(MMSTB)	(MWe)	(MW)	(TCF)	(MW)	(MW)	(MW)	(MW)	(MW)
Banten	19	-	-	261	-	-	72	465	2,46	1,753	-
DKI Jakarta	-	124	20	-	-	-	-	127	225	4	-
West Java	-	4,159	586	3,765	2,861	1	647	2,554	9,099	7,036	2,273
Central Java	1	997	918	1,344	813	-	1,044	2,233	8,753	5,213	-
DIY	-	-	-	10	-	-	5	224	996	1,079	-
East Java	-	5,378	264	1,012	525	-	1,412	3,421	10,335	7,907	-
Bali	-	-	-	262	-	-	15	192	1,254	1,019	320

Legend:
BCF : Billion Cubic Feet; MWe : Megawatt electric; TCF : Trillion Cubic Feet
MMSTB : Million Stock Tank Barrels; CBM : Coalbed Methane; MW : Megawatt

3.1.4. Energy Mix Policy (X4)

The final energy mix target is the expected portion of the energy mix for electricity generation at the beginning of the planning period in this research in 2020. The composition of the energy mix in 2020 comprised about 24% of NRE source, 54% of coal, 22% of gas, and 0.4% of fuel. In 2025, the energy mix portion is expected to consist of 23% of NRE, 55% of coal, 22% of gas, and 0.4% of fuel oil. Meanwhile, at the end of the planning period in 2029, the expected energy mix portion for electricity generation is 24%, 54%, 22%, and 0.4% for NRE, coal, gas, and fuel, respectively.

3.1.5. Technical Data (X5) and Generating Technology Cost (X6)

In this study, the assumption of technical data and the cost of generating technology used was based on the document Technology Data for the Indonesian Power (2017), which was the result of a collaboration between the Danish Energy Agency (DEA) and the National Energy Council (DEN) as shown in Table 3. The coal-fired (PLTU) ultra-supercritical type, which is the type of PLTU with the largest capacity of around 500 MW, has an investment cost of approximately 1.52 $/MW that must be incurred, with variable costs and fixed operation & maintenance (O&M) costs of 0.11 $/MW and 56.6$/MW, respectively. As for gas generation, the investment cost is 0.75 $/MW. For renewable energy generation, waste generation technology (PLTSa) has the most expensive investment cost of 8.4 $/MW, followed by natural gas (PLTP) with an investment cost of 4.5 $/MW and biomass with an investment cost of 2.5 $/MW, as well as hydropower with an investment cost of 1.9 $/MW. Meanwhile, for PLTS and PLTB, the investment costs are estimated at 1.25 $/MW and 1.25 $/MW.

Table 3 Data on technical and financial assumptions of power generation technology

Power Plant Technology	Investment cost $/MW	VarVariableM Cost $/MWh	Fixed O&M Cost k $/MW	Efficiency %	Size MW
Subcritical coal plant	1.65	0.13	45	34	50
Combined cycle gas turbine plant	0.75	0.13	23	56	10
Geothermal power plant	4.50	0.37	20	-	20
Biomass power plant	2.50	3.00	48	29	10
Waste power plant	8.40	-	277	35	20
Wind	1.88	-	60	-	-
Solar	1.25	-	15	-	-
Run of river hydro	1.90	0.50	53	33	-

3.1.6. Fuel Price (X7)

The government has set the Domestic Market Obligation (DMO) for coal at $ 70/ton for high-quality coal and $ 43/ton for low-grade coal in the Decree of Minister of Energy and Mineral Resource No. 1395 K/30/MEM/2018 concerning the Selling Price of Coal for the Provision of Electric Power for Public Interest. Based on the feedback from PLN, coal prices (including transportation costs) were set at around $50/ton for 2018 and 2019, equivalent to $2.8/GJ (assuming a calorific value of 4,218 kcal/kg). PLN continued to increase following projections in World Energy Outlook 2017 for growth in the coming years. Based on the Minister of Energy and Mineral Resources No. 58 of 2017 concerning the Selling Price of Natural Gas Through Pipes in Downstream Oil and Gas Business Activities in 2020, the prices of Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG) were set at $8.1/MMbtu or equivalent to $7.67/GJ. As for future progress, it is based on trends from World Energy.

3.2. Optimization of the Power Plant Development Planning Model

3.2.1. Addition of Generating Capacity

The results of the projected addition of generating capacity if the installed capacity and the planned generators were not optimized (*business-as-usual*) are shown in Table 4. These results indicate that during the 2020–2029 period, there would be an additional generating capacity of 20,289 MW. In this scenario, the addition of generating power is still prioritized over expanding coal-fired (PLTU) and natural gas generators (PLTGU).

Figure 2 shows the composition of installed generators in 2029, where the coal plant is 56.07%, natural gas is 28.48%, the utilization of NRE is 14.66 %, and the rest is fuel at 0.79%. There will be a decrease in the composition of generators sourced from coal in the next ten years compared to the current design of generators by 2%, natural gas by 2.5%, and the composition of renewable energy plants by 4.5%.

Table 4 Projection of Scenario 1 Power Generation Development (in units of MW)

Generator Type	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	Total
Coal	1,306	3,900	924	-	1,000	1,660	-	-	1,000	1,000	10,790
Diesel	-	-	-	-	-	-	-	-	-	-	-
Geothermal	-	-	10	120	65	395	130	350	170	880	2,120
Hydro	41	152	68	100	115	108	12	-	-	-	596
Waste	10	5	-	35	183	-	-	-	-	-	233
Gas	1,312	650	880	1,130	200	-	-	-	-	800	4,972
Pump Storage	-	-	-	-	52	52	76	94	-	-	274
Solar	-	-	60	270	50	310	-	-	-	-	690
Wind	-	-	23	60	400	130	-	-	-	-	613
Total	2,669	4,707	1,965	1,715	2,065	2,655	218	444	1,170	2,680	20,289

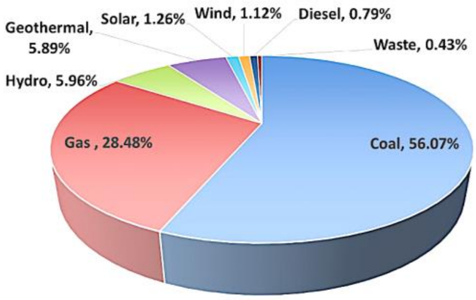

Figure 2 Projection of Scenario 1 power generation composition in 2029

Simulation results in capacity optimization only cover the investment, as shown in Table 5. These results indicate that during 2020–2029, there was an additional generating capacity of 22,824 MW. Compared with the projection development generator on business-as-usual simulation (Scenario 1), the additional generator in Scenario 2 is still prioritized on the PLTU with a total addition of 9,790 MW and has an additional PLTGU that is significant with the whole tallying of 7,428 MW.

The composition of installed generators in 2029 for Scenario 2 is shown in Figure 3. These results indicate that the configuration of generator coal becomes as high as 51.83%, natural gas at 31.51%, and utilization of new renewable at 15.90%. There will be a drop in the composition of generator-type coal as big as 6.25% and an increase in the composition of natural gas generators by 0.71% and renewable energy by 5.78% in the next ten years, compared to the current generator composition.

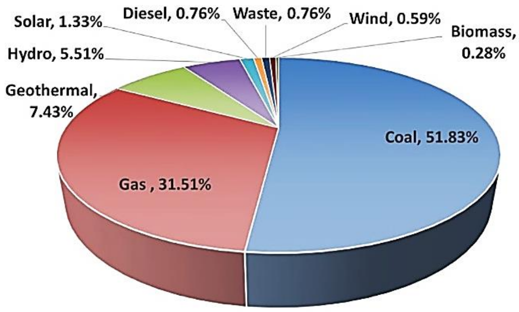

Figure 3 Projected Composition of Scenario 2 Generator in 2029

Table 5 Projection of Scenario 2 Power Generation Development (in units of MW)

Generator Type	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	Total
Coal	1,306	3,900	924	-	1,000	1,660	-	-	1,000	-	9,790
Diesel	-	-	-	-	-	-	-	-	-	-	-
Geothermal	94	55	86	120	286	1,333	130	350	170	525	3,148
Hydro	41	152	68	100	110	58	12	-	-	-	541
Waste	111	60	36	46	183	-	-	-	-	-	435
Gas	3,768	650	880	1,130	200	-	-	-	-	800	7,428
Pump Storage	7	18	-	-	52	52	-	94	-	-	223
Solar	663	-	50	-	-	50	-	-	-	-	763
Wind	-	87	-	50	200	-	-	-	-	-	337
Biomass	159	-	-	-	-	-	-	-	-	-	159
Total	6,149	4,922	2,044	1,446	2,031	3,153	142	444	1,170	1,325	22,824

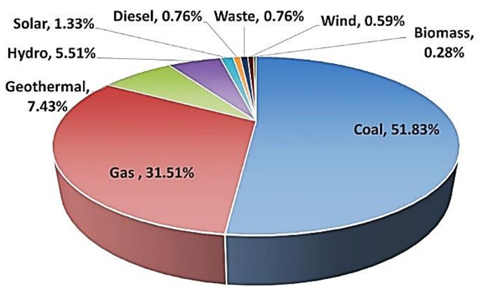

Figure 4 Projected Composition of Scenario 2 Generator in 2029

Table 6 shows the projected results of additional generating capacity for Scenario 3. From the results obtained during 2020–2029, other capacity generators with a total of 15,035 MW are available. Compared to the results in Scenario 1 and Scenario 2, there is only an addition of a coal generator(PLTU) in 2028 and 2029 in Scenario 3, with a total accumulation of 1,010 MW. Meanwhile, the addition of natural gas generators (PLTGU) is extensive, with a complete addition as significant as 9,085 MW. For the advancement of renewable energy plants in Scenario 3, the results obtained the addition of a geothermal generator (PLTP) with a total accumulation of 3,018 MW, PLTSa of 539 MW, PLTS, and PLTB with a complete complement of 711 MW and 487 MW, respectively. There is potential for another renewable energy generator type biomass (PLTBm) of about 159 MW.

Figure 4 indicates that the composition of coal generators and natural gas become as significant as 42.28% and 39.89%, respectively. Meanwhile, the utilization of renewable energy is only 16.95%, and fuel usage is 0.88%. Compared to the generator's composition at this time, a drop will occur in the composition of coal-type generators by 15.8% and an increase in the composition of natural gas generators by 9.09%, as well as renewable energy generators by 6.83%, in the next ten years.

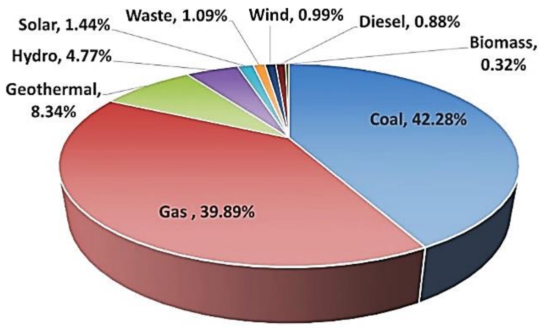

Figure 5 Projected composition of Scenario 3 generation in 2029

Table 6 Projection of Scenario 3 Power Generation Development (in units of MW)

Generator Type	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	Total
Coal	-	-	-	-	-	-	-	-	542	468	1,010
Diesel	-	-	-	-	-	-	-	-	-	-	-
Geothermal	94	55	198	46	609	1,484	146	191	196	-	3,018
Hydro	-	-	-	-	-	-	-	-	-	-	-
Waste	111	55	36	16	-	-	-	-	-	322	539
Gas	500	-	303	1,424	948	3	1,552	1,730	1,328	1,297	9,085
Pump Storage	25	-	-	-	-	-	-	-	-	-	25
Solar	711	-	-	-	-	-	-	-	-	-	711
Wind	-	87	-	-	-	200	200	-	-	-	487
Biomass	141	18	-	-	-	-	-	-	-	-	159
Total	1,582	215	537	1,486	1,557	1,687	1,898	1,921	2,066	2,087	15,034

The total projection numbers of each scenario represent the entire generation capacity from 2020 through 2029. The numbers for each design varies, where Scenario 1 has the most capacity since there has been no intervention from the Balmoral model, as it relied on the existing circumstances created by PT PLN. On the other hand, Scenario 2 has been intervened by the model in the remaining investment in developing the optimum generating capacity. Meanwhile, Scenario 3 yielded a power capacity of 15,034 MW since it was based on installed generating capacity, and the model has optimized all investments in developing capacity development.

Since the Balmoral model focused on optimizing the composition of the generator types; therefore, it can be seen in the comparison results of the three scenarios that the renewable energy generator type appeared in all scenarios. However, the projection of additional generators in Scenario 1 and Scenario 2 still prioritized generators powered by the burning fossils like coal (PLTU) and natural gas (PLTGU). Meanwhile, in Scenario 3, the projection of an additional generator is very optimizing on the potential NRE source. It showed the total score of the most significant extra renewable energy generator and the most diminutive additional coal generator compared to the other two scenarios. Another thing to pay attention to is when the addition of a renewable energy generator is considered in the optimization of power generating capacity's development planning, the composition of natural gas plants will increase. It occurs because fuel generators generally have a flexible operation faster than other thermal generators. Thus, it is necessary to add gas generators to anticipate the fluctuation of generation from renewable energy generators, specifically solar and wind generators.

3.2.2. Cost Analysis

In this study, the optimization of generating capacity development planning was obtained as a power plant capacity development plan with the lowest cost yet still fulfilling the power adequacy and reliability criteria. In this case, the lowest supply cost was achieved by minimizing the Net Present Value (NPV) of all cost components, including investment, fuel, O&M, and unserved energy (USE) costs (Muthahhari et al., 2019).

The investment costs for each scenario were obtained using the estimation of technology costs shown in Table 3. The overall generation cost for planning the development of generators in the Java-Bali power system during 2020–2029 Scenario 1, Scenario 2 and Scenario 3, was estimated at around IDR 2.736 trillion, IDR 2.782 trillion, and IDR 2.471 trillion, respectively. Table 7 summarizes the detailed cost calculations.

Table 7 Projection comparison of total costs

Cost Components	Total Cost (IDR Million)		
	Scenario 1	Scenario 2	Scenario 3
Investment Cost	1,027,137,581.60	1,106,630,512.38	901,299,894.69
Fixed O&M Cost	277,878,282.60	291,561,588.57	218,989,124.50
Variable O&M Costs	6,218,250.31	5,505,324.79	5,957,667.44
Fuel Cost	1,424,902,521.02	1,378,317,475.59	1,344,983,684.89
Total	2,736,136,635.52	2,782,014,901.33	2,471,230,371.53

The analysis of investment costs in the three scenarios shows that Scenario 3 has the lowest average price of electricity generation compared to other scenarios, as shown in Figure 5. Therefore, it can be concluded that optimizing the current electricity generation plan can reduce the essential generation cost. However, the average value of the Electricity Generation Basic Cost (EGBC) for generation from all scenarios is still higher than the realization of the Cost of Generation (BPP) value for the Java-Bali system in 2019, IDR 957.66/kWh. It shows that using renewable energy can potentially increase electrical energy costs. Therefore, optimization of generation planning also needs to be supported by regulations that regulate the purchase price of electricity from renewable energy, so it is hoped that increasing EGBC due to electricity prices from renewable energy can be avoided.

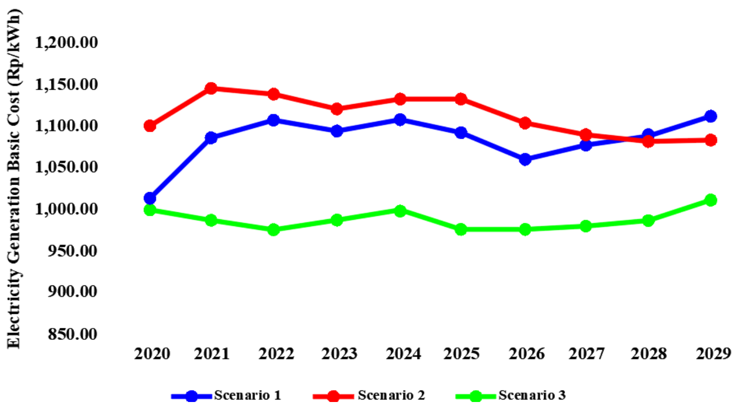

Figure 6 Comparison of projected costs of electrical energy production

4. Conclusions

The scenario for development planning of generating capacity with optimal utilization of renewable energy sources, with efficient costs, is in Scenario 3. Projection of additional generating capacity in Scenario 3 projects the composition of renewable energy of 16.95 % at the end of the 2029 planning period. From the analysis of investment costs, Scenario 3 becomes the scenario with the lowest total investment cost of IDR 901 trillion, with a whole additional generating capacity of 15,035 MW for 2020 – 2029. From the projection of the average cost of electricity production, Scenario 3 becomes the most economical scenario compared to other proposed scenarios, with an average value of the cost of electricity production for the planning period 2020–2029 of IDR 987.70/kWh.

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