International Journal of Advanced Science and Technology
Vol. 29, No. 8, (2020), pp.4535-4541

Optimization Of Generation Expansion Planning For The Achievement Of Renewable Energy Target

[1] Joanna Francisca Socaningrum, [2] Mohammed Ali Berawi M.Eng.Sc., Ph.D.
[1] University of Indonesia, [2] University of Indonesia
[1]francisca.joanna@gmail.com,[2] maberawi@eng.ui.ac.id

Abstract

Electricity has become one of the important needs for the society. However, the increasing concern about global warming has made various policies to reduce CO2 emissions aimed at reducing the level of global warming, especially from the electricity sector. The Java-Bali electricity system is the largest electricity system in Indonesia. In 2019 the total electricity demand in the Java-Bali system is 189,606 GWh and the peak load is 27,973 MW. At present the energy mix in Java-Bali is still dominated by coal by 70%, and natural gas by 21.22%, while the utilization of renewable energy is only 7.71% and the rest are still using fuel by 0.14%. To increase the utilization of renewable energy sources and reduce the use of fossil fuels in meeting electricity demand, the government set a target of the energy mix in Indonesia for renewable energy by 23% in 2025 and 31% in 2050. Java-Bali itself has quite large potential in renewable energy sources. Therefore, to be able to fulfill the electricity demand by utilizing renewable energy sources, it is necessary to develop an optimal electricity system development planning strategy to obtain the most efficient investment plan. This paper evaluates several scenarios to find the potential future development of Java Bali electricity system with considering the potential of renewable energy source on a least cost basis.

Index Terms— *Electricity, renewable energy, planning*

I. INTRODUCTION

Along with the increase in economic growth and social welfare, the needs for electrical energy also continues to increase. To be able to meet the needs of electrical energy, we need an appropriate electricity infrastructure development plan. Optimize the generating units installed in the system with a minimum total cost and fulfill certain specified constraints.

Recently, the increasing concern about global warming has made various policies to reduce CO2 emissions aimed at reducing the level of global warming, especially from the electricity sector. The negative effect of CO2 emission on the environment, as well as the availability of fossil fuel supply in the future, needs to be considered in generation expansion planning (GEP). Many countries have been attempting to convert their energy production to sustainable energy, such as wind energy, tidal energy, solar energy, and geothermal energy and many others. Sustainable energy will play a significant role in the future for energy demand issues and has the potential to reduce Indonesia's electricity problems [5].

Therefore, to increase the utilization of renewable energy sources and reduce the use of fossil fuels in meeting the needs of electricity, the Government of Indonesia has enacted Law No. 30 of 2009 concerning Electricity which states that primary energy sources contained in the country and / or originating from abroad must be utilized optimally in accordance with national energy policies to ensure the sustainable supply of electricity, where such utilization is prioritized for new and renewable energy sources. The government in the regulation No. 79 of 2014 concerning about National Energy Policy (KEN) sets targets for the use of renewable energy (EBT) of at least 23% in 2025 and 31% in 2050.

The Java-Bali electricity system is the largest electricity system in Indonesia. Based on data from PT. PLN (Persero), the peak load of Java-Bali electricity system in 2019 was 27,973 MW with the net capacity was 36,933 MW. The peak load increases by 3.34% compared to 2018. While the electricity sales in 2019 was 189,606 GWh with the growth 3,70% and estimated will increase with average of 4.28% per year from 2020 to 2029. Fig. 1 shows the load profile of Java-Bali electricity system. the daily load profile in the weekdays (Monday to Friday) and the weekend (Saturday and Sunday) is quietly similar. The peak load occurs on weekdays at 06:00 PM. According to Fig. 2 the composition of the net capacity in Java Bali electricity system was dominated by coal by 58%, natural gas by 31%, renewable energy by 10% and the rest are fuel by 1%.

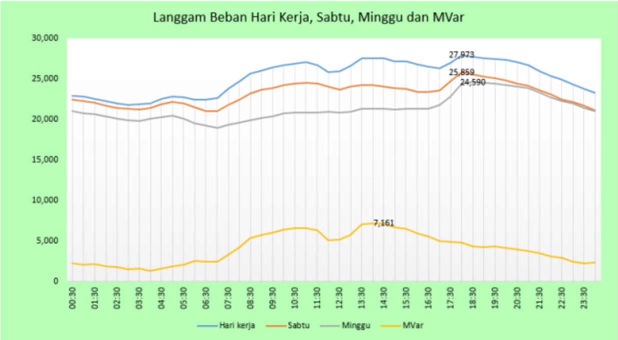

Fig. 1. Load profile of Java-Bali (in Bahasa)
Source: PT. PLN (Persero) (2020)

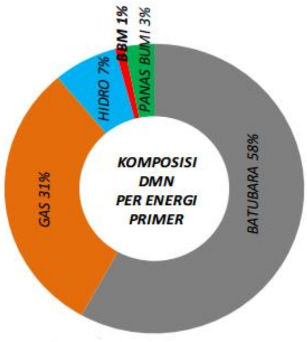

Fig. 2. Java-Bali existing net capacity composition (in Bahasa)
Source: PT. PLN (Persero) (2020)

Fig. 3 is the electricity generation mix of Java-Bali in 2019. The chart shows that the energy mix is currently also dominated by coal by 70%, and natural gas by 21.22%, while the utilization of renewable energy is only 7.71% and the rest are still using fuel by 0.14% [7]. When compared with the potential of existing renewable energy sources, the use of renewable energy to meet electricity energy needs in the Java-Bali system is currently still relatively low. Therefore, to support the government policies in increasing the use of renewable energy sources, it is necessary to develop a generation expansion planning (GEP) model with optimal utilization of renewable energy.

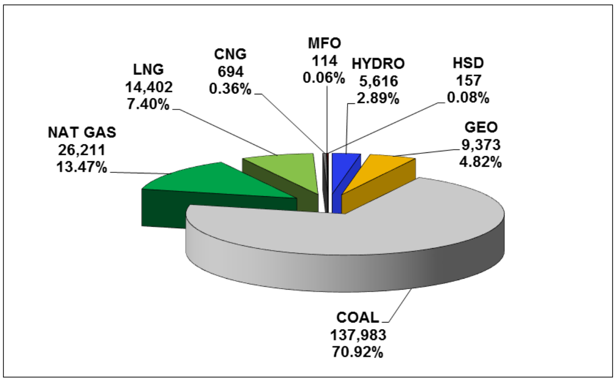

Fig. 3. Java-Bali generation mix 2019 (in Bahasa)
Source: PT. PLN (Persero) (2020)

Generation expansion planning (GEP) is one of the important parts in electricity power system planning. GEP is a power plant mix problem that identifies what, where, when, and how new generating facilities should be installed and when old units be retired over a specific planning horizon. GEP ensures that the quantity of electricity generated matches the electricity demand throughout the planning horizon [6]. The main objective of the GEP is to ensure the availability of electricity that is sufficient for electricity needs with the lowest costs in the future by considering both technical and non-technical constraints [1].

There have been various studies in GEP which conducted to analyze the development and use of renewable energy in meeting the needs of electrical energy. A research study to solving long-term GEP problems in China proposed Statistical Residual Load Duration Curve (S-RLDC) to deal with the uncertainty characteristic of wind and PV, in which the technique of convolution is adopted to obtain the probability distribution of renewables also wavelet decomposition is applied to reveal the fluctuation amplitude of renewables, and further to determine the flexible capacity requirement for mitigating this fluctuation [8]. There is also a research which proposes a GEP models using a method based on equivalent load carrying capability (ELCC) to evaluate the capacity value of variable generation such as wind and PV and presented a multi-area generation expansion co-optimization model of variable generation and conventional power sources [2]. A researcher from Romania builds the GEP mixed-integer linear programming (MILP) problems using Non-linear programming (NLP) problems as initial model with considering wind power plants (WPP) as the new generating units that are possible to be built [3]. Other research work in Canada proposed a linear programming model for coordinated generation and transmission expansion planning considering the uncertainties of renewable energy resources and investigated the impact of different carbon emission reduction policies on the system planning [9]. Moreover, a researcher from Iran proposed the GEP models optimization by considering the costs of fossil fuel power plants and the carbon tax [4].

II. METHODOLOGY

In this research, we focus on the Long Term GEP in Java-Bali electricity system with considering the potential for renewable energy and the energy mix target. The Java-Bali electricity system is divided into five regions, namely Jakarta & Banten, West Java, Central Java & Yogyakarta, East Java and Bali.

This research was carried out in two stages. At the first stage, an evaluation of secondary data is carried out. The aim is to obtain variable data needed as input from the model to be created. The second stage aim to find out the most optimal investment scenario. The economic optimization model is applied for optimizing capacity expansion and merit order dispatch on a least cost basis. The GEP models in this research was simulated using Balmorel Model and GAMS (General Algebraic Modeling System) as the solver and will be simulate for planning horizon 2020 – 2029. The costs of system generation expansion and fuel cost have been proposed as the objective functions. In GAMS the objective function is part of the equations in the model. Each of these cost functions is defined in a simple mathematical form as follows:

$$C^{INV} = \sum_{i \in I} b_i^{INV} (p_i^{max} + q_i^{max}) \tag{1}$$

$$C^{fuel} = \sum_{i \in I} a_i^{fuel} fi \tag{2}$$

There will were three scenarios given in Table I. First, The Business-as-Usual scenario, which is based on the capacity expansion plans data from PLN. In the second scenario, only capacity specified in data from PLN as projects already committed or under construction projects is considered, while the rest of the investment in power capacity development is optimized by the model. The third scenario builds on the existing capacity with all the investment in power capacity development is optimized by the model. The external costs of pollution and externalities related to the emissions of CO2 are not considered in the investment and dispatch optimization.

TABLE I. SIMULATION SCENARIOS

No.	Scenario	Description of scenario
1	Business as Usual	Existing capacity + all planned projects
2	Ongoing & committed projects optimization	Existing capacity + ongoing & committed projects + optimization
3	Full optimization	Existing capacity + optimization

The assumption of demand forecast for Java-Bali electricity system used in this model is based from data from PLN. While for the fuel price are based on Indonesia Ministerial Decree. For the investment cost (the development for the new generation technologies) based on the data from the technology catalogue assumptions. Then, for all fuel or energy potential data and energy mix target needed for the scenario is taken from Rencana Umum Ketenagalistrikan Nasional (RUKN) 2019-2038 given in Table II.

TABLE II. ENERGY POTENTIAL

	Banten	Jakarta	West Java	Central Java	Yogyakarta	East Java	Bali
Natural Gas (BCF)	-	124	4,159	997	-	5,378	-
Natural Oil (MMSTB)	-	20	586	918	-	264	-
Geothermal (MWe)	365	-	3,765	1,344	10	1,012	262
Hydro (MW)	-	-	2,861	813	-	525	-
CBM (TCF)	-	-	1	-	-	-	-
Microhydro (MW)	72	-	647	1,044	5	1,412	15
Bioenergy(MW)	465	127	2,554	2,233	224	3,421	192
PV(MW)	2,461	225	9,099	8,753	996	10,335	1,254
Wind (MW)	1,753	4	7,036	5,213	1,079	7,907	1,019
Wave (MW)	-	-	2,273	-	-	-	320

III. RESULTS AND DISCUSSION

A. *Capacity expansion*

As mentioned in the methodology, Business as Usual scenario simulates the system based on the RUPTL development and serves as reference for the other scenarios. While for the other scenarios, the optimizer software was used to find the optimal capacity and dispatch strategy on least cost basis. Fig. 4 shows the development of the installed capacity in the planning horizon 2020-2029. The total installed capacity Business as Usual scenario in the final year of the 2029 period was 54,624 MW with a composition 30,625 MW (56.1%) coal, 15,557 MW (28.5%) natural gas, 3,258 MW (6.0%) hydropower, 3,216 MW (5.9%) geothermal, 690 MW (1.3%) solar, 613 MW (1.1%) wind, 233 MW (0.4%) waste 432 MW (0.8%) fuel. For Ongoing & committed projects optimization scenario, the total installed capacity in 2029 was 60,901 MW with a composition 29,625 MW (48.6%) coal, 19,133 MW (31.4%) natural gas, 3,152 MW (5.2%) hydropower, 4,145 MW (6.8%) geothermal, 2,157 MW (4.1%) solar, 1,302 MW (2.1%) wind, 159 MW (0.3%) biomass, and 435 MW (0.7%) muni waste, and 432 MW (0.7%) fuel. While for the full optimization scenario, the total installed capacity in 2029 was 50,625 MW with a composition 23,682 MW (46.8%) coal, 16,430 MW (32.5%) natural gas, 2,350 MW (4.6%) hydropower, 4,427 MW (8.7%) geothermal, 1,876 MW (3.7%) solar, 687 MW (1.4%) wind, 159 MW (0.3%) biomass, and 582 MW (1.1%) muni waste, and 432 MW (0.7%) fuel.

As can be seen, there are major differences in what type of power plants are prioritized by the model and deemed optimal compared to the Business as Usual scenario. The main observation is that much more renewable energy is coming online in other scenarios compared to Business as Usual scenario. Biomass plants are considered competitive in the optimization scenario depending on the biomass price and power plant cost assumed, even with no consideration of externality cost or higher fossil fuel prices. The result also finds investment in solar, wind and geothermal capacity feasible in all scenarios. The addition of the new renewable energy power plant reduces the need for fossil fuel plants. For the total installed capacity, we can see that Scenario 3 has the lowest amount of installed capacity compared to the other scenarios.

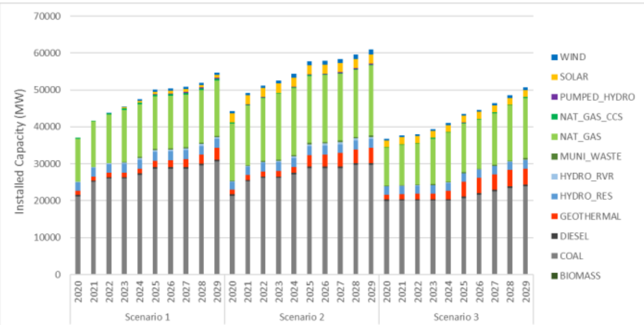

Fig. 4. Comparison of Installed Capacity

Fig. 5 – Fig. 7 is the energy compositions based on the installed capacity in 2029. From these results, it can be seen that the effect of considering the potential of renewable energy against the GEP combination results can reduced the amount of coal power plants mix from 56.07% to 46.78%. Besides that, renewable energy mix increase from 14.7% to 19.9% when the renewable energy included in GEP optimization. Another thing to be noticed is that when the renewable energy plant is included in the GEP optimization, the natural gas mix increase from 28.5% to 38.5%. The increase in the gas mix aims to anticipate generation fluctuations from the variable renewable energy power plants (solar and wind). To anticipate these fluctuations, a power plant with a ramping-rate capability is needed, which is owned by gas power plants

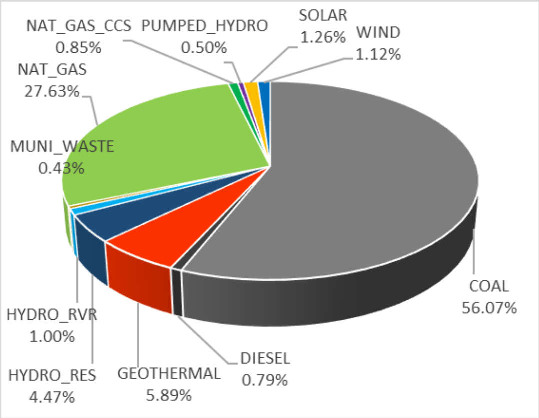

Fig. 5. Power plants mix – Scenario 1

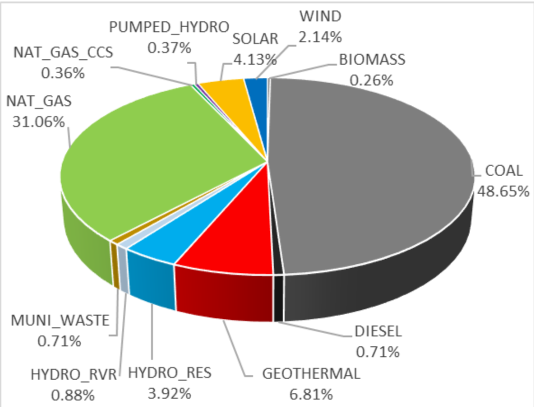

Fig. 6. Power plants mix – Scenario 2

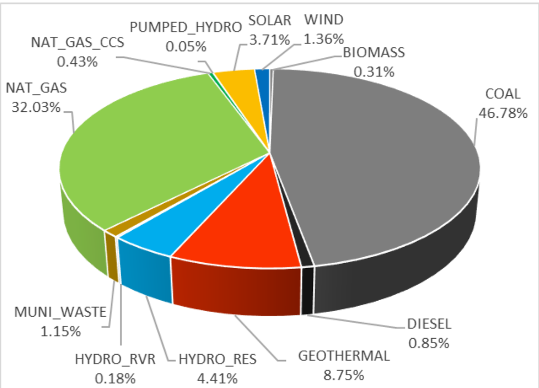

Fig. 7. Power plants mix – Scenario 3

As the growth of the electricity demand, the total electricity generation in Java Bali system is increasing during the period 2020 – 2029. From the result of the electricity generation shown in Fig. 8, it can be seen that the total electricity generation is increasing to reach 302,000 GWh in 2029.

ISSN: 2005-4238 IJAST

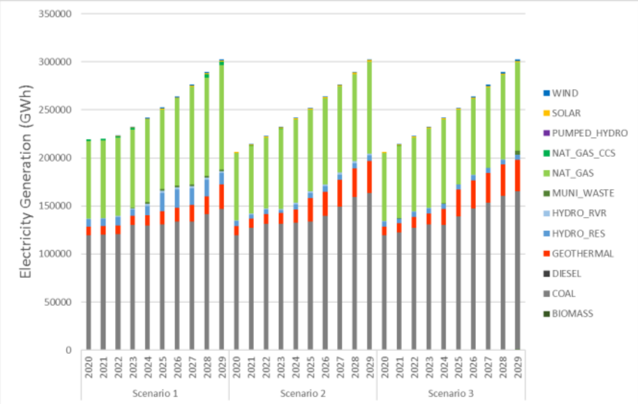

Fig. 8. Electricity Generation

B. *Cost Analysis*

According to the results illustrated in Fig. 9, it was found that the full optimization scenario has the lowest capital cost compared to other proposed scenarios. As can be seen in Fig. 3, this is due to lowest coal power plant capacity expansion, because the investment cost of coal power plant is higher than the investment cost of renewable energy. While, the ongoing & committed projects optimization scenario become the most expensive scenario among the other proposed scenarios.

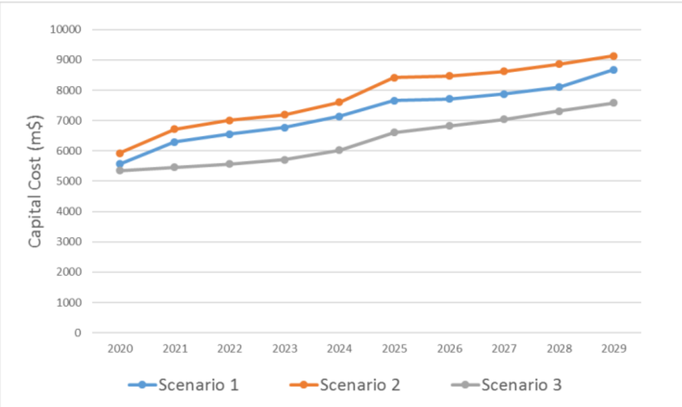

Fig.9. Capital Cost

Fig. 10 shows that the fuel costs of business as usual scenario are higher than the other scenarios. As also can be seen in Fig. 7 the composition of natural gas in the business as usual scenario is higher than in the other scenarios. This is what causes the high cost of fuel, because gas prices are more expensive than the other fuels such as coal. Comparing Business as Usual scenario and Full optimization scenario, it is explicitly presented that operating more renewable energy will definitely reduce the energy to be supplied from natural gas and coal power plant which in turns reduce the fuel consumption and fuel cost.

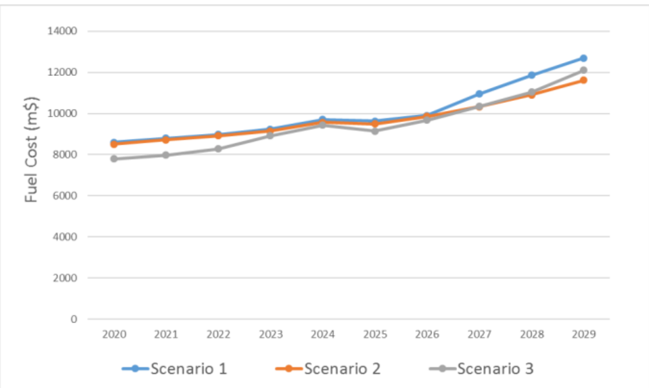

Fig. 10. Fuel Cost

Fig. 10 shows the development of the electricity generation cost of the Java-Bali power system for the years 2020 - 2029, across the different scenarios, expressed in Rp/kWh. The cost components considered are capital cost, fixed operation & maintenance cost, variable operation & maintenance cost, and finally fuel cost. From these results, it can be seen that the full optimization scenario has the lowest value of electricity generation cost compared to the other proposed scenarios. The average value of electricity generation cost in Business as Usual scenario is Rp1,084.81/kWh. While the average value of electricity generation cost in Full optimization scenario is Rp. 987.70/kWh. Ongoing & committed projects optimization scenario has the highest average value of electricity generation cost, it was Rp. 1,114.17/kWh.

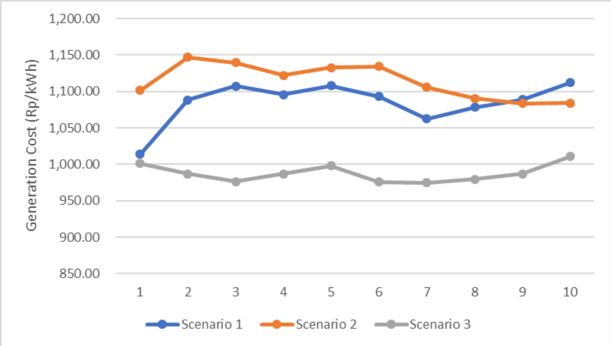

Fig. 11. Electricity Generation Cost

IV. CONCLUSION

The potential development of the Java Bali electricity system is very different across the scenarios analyzed. The Business as Usual scenario, which based on assumptions from PLN's data is largely based on the addition of coal power plants and gas to supply the demand. On the other hand, based on the assumption described and the least cost optimization from the model, there are potential for renewable energy sources to play a role in the development of the supply in the island. Looking at the total cost of the system, the most expensive scenario is the ongoing & committed projects optimization scenario. While the full optimization scenario become the cheapest scenario compared to the other proposed scenarios.

With the renewable energy penetration, this can affect several things, such as emissions production, reserve margin, and electricity generation cost. The consideration of renewable energy potentials, results in reducing the need for fossil fuel plants. Since the external costs of pollution and externalities related to the emissions of CO2 are not considered in this model, the composition of the fossil fuel plants (coal and gas) is still dominating the potential development of the Java Bali electricity system. Considering the renewable energy potential also considering the external costs of pollution and externalities related to the emissions of CO2 could be alternative solution to give a better result in the GEP model to support further higher integration of renewable energy and also support the reduction of the emissions production, in particular in the form of low-cost finance.

REFERENCES

[1] A. Muthahhari, L.M. Putranto, Sarjiya, F.S. Anugerah, A. Priyanto, S. Isnandar, and I. Savitri, "Long-Term Generation Expansion Planning in Sulawesi Electricity System Considering High Share of Intermittent Renewable Energy Resource," in 11th International Conference on Information Technology and Electrical Engineering (ICITEE), 2019

[2] B. Yuan, S. Wu, J. Zong, "Multi-Area Generation Expansion Planning Model of High Variable Generation Penetration," in 2017 2nd International Conference on Power and Renewable Energy, pp 645-648

[3] C. A. Sima, G. C. Lazaroiu, V. Dumbrava, M. Tirsu, V. Galbura, "Integration of Renewable Energy Sources using Generation Expansion Planning," in 14th International Conference on DEVELOPMENT AND APPLICATION SYSTEMS, Suceava, Romania, pp. 6-10, May 2018

[4] H. Akbarzade, T. Amraee, "A Model for Generation Expansion Planning in Power Systems Considering Emission Costs," in 2018 Smart Grid Conference (SGC)

[5] M.A. Berawi, P. Miraj, A. R. B. Berawi, Silvia, F. Darmawan, "Towards Self-Sufficient Demand In 2030: Analysis Of Life-Cycle Cost For Indonesian Energy Infrastructure", International Journal of Technology, 2016

[6] O. M. Babatunde, J. L. Munda, Y. Hamam, "A comprehensive state-of-the-art survey on powergeneration expansion planning with intermittent renewable energy source and energy storage," International Journal of Energy Research, pp. 1–30, 2019

[7] PT PLN (Persero) Unit Induk Pusat Pengatur Beban, "Evaluasi Operasi Sistem Jawa Bali Tahun 2019", 2020 (in Bahasa)

[8] W. Shengyu, C. Lu, Y. Xiaoqing, and Y. Bo, "Long-term Generation Expansion Planning underUncertainties and Fluctuations of Multi-type Renewables," in 2015 IEEE 5th International Conference on Power Engineering, Energy and Electrical Drives, pp. 612-616

[9] V. Asgharian, M. Abdelaziz, "A Linear Programing Model for Coordinated Low Carbon Generation and Transmission Expansion Planning," in 2017 IEEE Electrical Power and Energy Conference (EPEC)