IJECBE (2024), **2**, **4**, 438–453
Received (3 July 2024) / Revised (5 July 2024)
Accepted (5 July 2024) / Published (30 December 2024)
https://doi.org/10.62146/ijecbe.v2i4.73
https://ijecbe.ui.ac.id
ISSN 3026-5258

International Journal of Electrical, Computer and Biomedical Engineering

RESEARCH ARTICLE

Techno-Economic Optimization Study of Renewable Energy Planning in Buru Island Electricity System

Faizatul Hasanah Z Day,* Muhammad Gillfran Samual, Iwa Garniwa Mulyana K, and Budi Sudiarto

Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Depok, Indonesia
*Corresponding author. Email: faiza.zday@gmail.com

Abstract

One of the strategies to achieve Indonesia's NDC target in 2030 is through the development of renewable energy power plants, and the transition from fossil fuels to renewable energy. The use of diesel power plants, especially with the case on Buru Island as the only electricity supply, contributes to the production of emissions, and increases the Cost of Energy (CoE) of the utility system. On the other hand, Buru Island is rich in renewable energy potential, such as geothermal, hydropower, bioenergy, and solar energy. This study aims to design an optimal power generation system on Buru Island by considering the renewable energy mix, financial feasibility, reduction in the CoE of local electricity system, reduction in CO_2 emissions, and the potential load growth of the local industry, i.e. fisheries industry sector. This study utilizes HOMER software to obtain a power generation scenario that can supply the load with the most optimal renewable energy penetration, the lowest Levelized CoE (LCOE), and the lowest CO_2 emissions. Seven electrical systems on Buru Island were implemented to form 4 systems, namely an integrated system of 4 previously distributed systems, and 3 other distributed systems. The result of this research gives out the most optimum configuration of hybrid or complete renewable energy-based power plant configuration for each system. The configurations can reduce the CoE up to 20.17 cUSD/kWh, and up to zero CO_2 emission.

Keywords: Buru island, HOMER, hybrid, renewable energy, techno-economic

1. Introduction

Currently, fossil fuels still dominate the national energy mix, with coal accounting for 39.6%, followed by oil at 29.91%, and natural gas at 17.11%, while renewable energy has only reached 13.29% [1]. The dominance of fossil fuels has caused Greenhouse Gas (GHG) emissions in the energy sector to increase significantly. The government has committed to reducing GHG emissions in accordance with the global agreement stated in the Enhanced Nationally Determined Contribution (E-NDC) document to reduce emissions by 358 million tons of CO_2 by 2030. On the other hand, crude oil production continues to decline from year to year, with production recorded at 605 MBOPD or 221 million barrels in 2023. Meanwhile, crude oil exports were 21.3 million barrels and imports were 132.4 million barrels, up 38% and 26% respectively from the previous one [1]. The realization of fuel subsidies has fluctuated in the last 5 years, with the highest value in 2018 reaching 38.9 trillion Rupiah due to an increase in diesel oil subsidies. However, the subsidy decreased to 14.9 trillion Rupiah in 2020 due to the Covid-19 pandemic, and in 2021 it increased again to 16.2 trillion Rupiah and decreased again to 15.2 trillion Rupiah in 2022 [2].

To support economic growth, achieve NDC targets, and increase energy resilience and independence, the government continues to strive in energy diversification. In the national energy policy, the Government encourages the use of renewable energy, the implementation of energy efficiency, the use of low-carbon fuels, and the use of cleaner power generation technologies [3]. One of the largest uses of fuel is for Diesel Power Plants (DPP). The use of DPP on small islands causes the basic Cost of Energy (CoE) of the utility system to be very high, due to the high cost of transportation and logistics, including on Buru Island. Currently, 100% of the electricity supply on Buru Island comes from DPP. Therefore, Buru Island is chosen as a case model in this paper because it has high potential for renewable energy sources. The aim of this research is to design an optimal electricity generation system on Buru Island by considering the renewable energy mix, financial feasibility, reduction in local system BPP, reduction in CO_2 emissions and potential load growth for the fishing industry sector.

For electrification on islands or remote areas, the integration of Distributed Energy Resources (DER) is the wisest choice to produce sustainable and environmentally friendly energy. Solar, wind, and biomass energy sources are the most cost-effective for hybrid systems [4]. However, due to its intermittent nature, hybridization of various renewable energy sources combined with energy storage systems such as Battery Energy Storage System (BESS) can significantly improve system reliability. In a hybrid DPP-DER-BESS system, optimal sizing and performance assessment are important aspects of system design. This study aims to obtain an optimal design for a power generation system on Buru Island by considering the renewable energy mix, financial feasibility, reduction in CoE of the local electricity system, reduction in CO_2 emissions, and potential load growth for the local industry on the island, i.e. fisheries sector.

Several studies have been conducted to determine the optimal design of a hybrid power generation system, especially Solar PV system with BESS combined with diesel generators [4] , [5] , [6] , [7] , [8] , [9] , [10] , [11] , [12] , [13] , or system with Solar PV with BESS combined with biomass generation [14]. A software program, Hybrid Optimization Model for Electric Renewable (HOMER), will be used to perform system component measurements and economic optimization. The optimization objective is to determine the most optimal configuration of the hybrid electric power generation system by evaluating the Levelized Cost of Energy (LCOE), Net Present Cost (NPC), electrical parameters, renewable energy mix and emissions, compared to a standalone diesel system. NPC (Net Present Cost) and LCOE (Levelized Cost of Energy) are two financial indicators used by HOMER (Hybrid Optimization of Multiple Energy Resources) software to determine the performance and economic viability of hybrid energy systems. LCOE is the NPC divided by total energy production. So, changes in NPC will have a direct impact on LCOE.

NPC is defined as the present value of all system-related costs incurred over its lifetime, minus the present value of all revenues earned over its lifetime. These costs include capital costs, replacement costs, operation and maintenance costs, fuel costs, emission fines, and costs of purchasing power from the grid. Revenue includes residual value and network sales revenue.

Total NPC can be calculated using the following equation 1 :

$$C_{NPC} = \frac{C_{cap} + C_{rep} + C_{o\&M} + C_{other}}{CRF} \tag{1}$$

where C_{cap}, C_{rep}, $C_{o\&M}$, C_{other} represent the capital costs, replacement cost, operation and maintenance costs, and other costs (fuel costs, emissions penalties, and the costs of buying power from the grid), respectively. CRF determines the capital recovery factor, defined by:

$$i = \frac{i' - f}{1 + f} \tag{2}$$

where i is the real annual interest rate and N is the number of year.

In the HOMER software to calculate COE, the annual electrical energy production expenses are divided by the total consumed electrical energy produced, using the following equation:

$$COE = \frac{C_{ann,tot} - C_{boiler}\,H_{served}}{E_{served}} \tag{3}$$

where $C_{ann,tot}$, C_{boiler}, H_{served}, E_{served} define total annualized cost of the system, boiler marginal cost, total thermal load served, and total electrical load served, respectively.

The remainder of this paper is constructed as follows: Section 2 describes the data and methodology used in this paper, including the system configuration, renewable energy resources, and HOMER optimization. Section 3 includes simulation results and evaluation of performance criteria. Finally, conclusions are given in Section 4.

2. Research Methodology

2.1 Existing Generator and Load Profile

This study uses data and conditions of the electricity system on Buru Island, Maluku, by considering the potential for demand growth and the potential of cold storage for fisheries. The Buru Island Electricity System currently has 7 systems, namely the Namlea system, the Namrole system, the Namsisi system, the Mako system, the

Air Buaya system, the Leksula system, and the Waipandan system, which serve loads spread across 10 (ten) sub-districts on Buru Island with a total peak load of 16.16 MW, and a net capacity of 19.28 MW. The current average CoE on Buru Island is IDR 4,898.4/kWh, which is mostly influenced by fuel costs. The existing load profile of Buru Island is shown in Figure 1. Based on the load profile, the load is dominated by the household sector and the commercial sector, with peak loads occurring around 18:00 to 22:00.

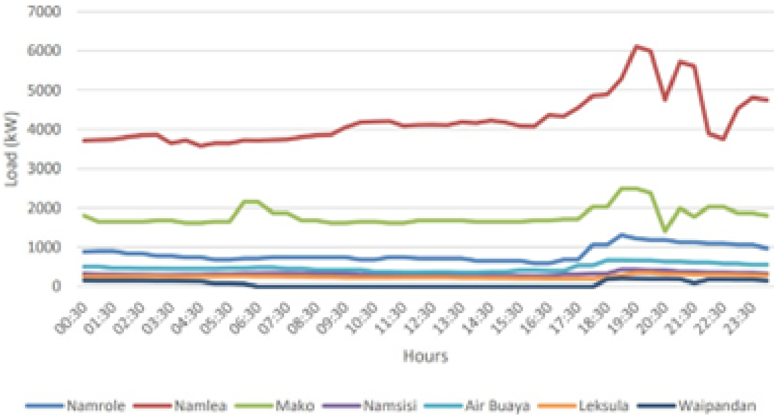

Figure 1. Daily Load Profile of Electrical System on Buru Island

2.2 *Renewable Energy Potential on Buru Island*

Buru Island has abundant renewable energy sources. The potential for geothermal energy sources reaches 10 MW, while hydro energy sources reach 18.3 MW, and the potential for biomass is 10 MW. However, there is a theoretical biomass potential on Buru Island with 51,971 hectares of production forest that can produce 1,273,304 tons of biomass resources annually, or equivalent to 611 MW. The area mostly functions as a settlement, agriculture and plantation with moderate vegetation density conditions. Another renewable energy potential owned by Buru Island is solar energy. Based on Global Horizontal Irradiation (GHI) data, the potential for solar energy (annual average) on Buru Island is 1895 kWh/m^2/year, and solar irradiation is 5.19 kWh/m^2/day. This figure is relatively higher than Jakarta, whose GHI value is 4.6 kWh/m^2/day.

2.3 *Design of Electricity Generation System on Buru Island*

In this study, the planning of the electricity system on Buru Island will be divided into 4 (four) systems, namely:

1. Namlea, Moko, Namrole, Wamsisi interconnection system;
2. Air Buaya system;
3. Leksula system; and
4. Waipandan system.

The design of the electricity generation system on Buru Island was carried out with the assumption that population growth for the Namlea, Namrole and Mako systems are quite high, with an average of 3.5%. While in other isolated systems such as the Air Buaya, Leksula, and Waipandan systems, the population growth is quite low, with an average of 1.5%. The Buru Island load profile for each system is shown in Figure 2 to Figure 5.

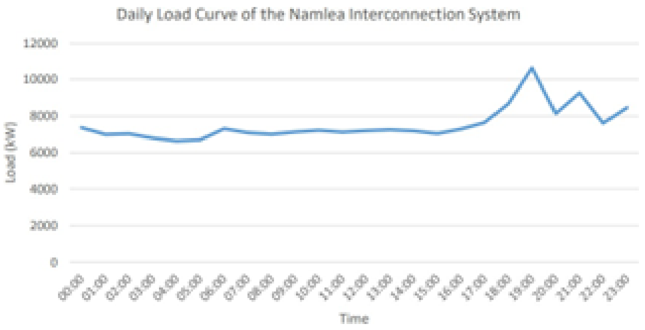

Figure 2. Daily Load Curve of Namlea, Moko, Namrole and Wamsisi Interconnection System

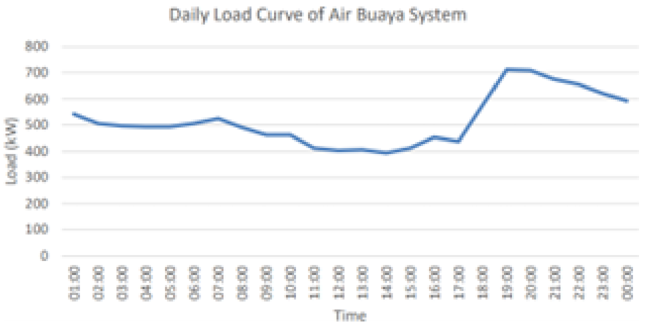

Figure 3. Daily Load Curve of Air Buaya System

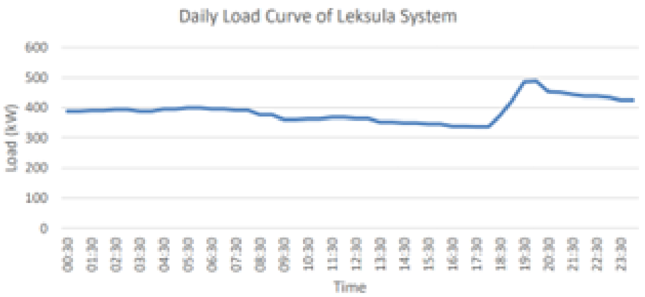

Figure 4. Daily Load Curve of Leksula System

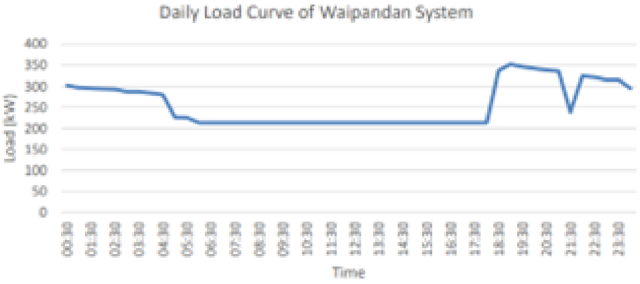

Figure 5. Daily Load Curve of Waipandan System

The development of the power generation system is carried out using the methodology shown in Figure 6. Data collection is carried out to collect the inputs needed for the optimization process, namely load profiles, existing DPP data, solar radiation profiles, geothermal power plant potential, hydro power plant potential, biomass potential, and costs related to each type of generation. In this study, three power generation system configurations were selected to obtain the optimum combination, namely 100% using existing DPP, 100% renewable energy penetration, and the lowest cost with renewable energy penetration optimization. HOMER performs simulations and optimizations based on specifications to identify the best combination design that provides the best performance in terms of cost and technical aspects. The results are then sorted from the highest renewable energy penetration ratio. Each sorted result is then filtered through iterations based on several factors to determine the configuration that best suits the research objectives, including a CoE that is lower than the current CoE.

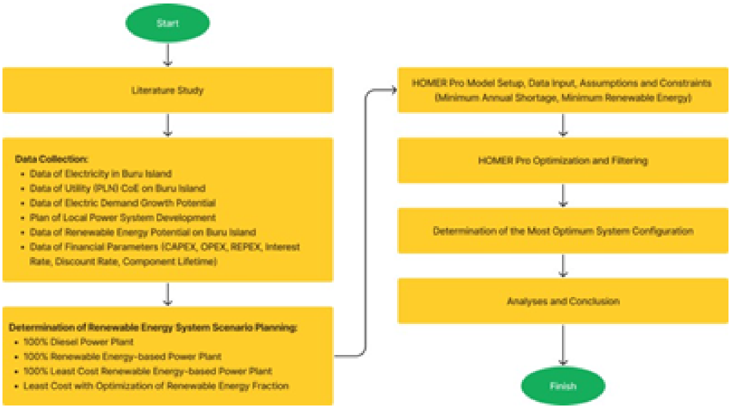

Figure 6. Flowchart of the Research Methodology

3. Simulation Results

3.1 Economic and Financial Parameters

In conducting HOMER simulation and optimization, values of several variables must be determined by proper assumption. The financial parameters required include Capital Expenditure (CAPEX) value, Operational Expenditure (OPEX) value, Replacement Expenditure (REPEX), discount rate, and inflation rate. The economic parameters of each generating component can be seen in Table 1. The rupiah exchange rate is IDR 16,000/USD, while the cost of diesel fuel uses the assumption of IDR 10,000/liter, a discount rate of 10%, and an inflation rate of 3%. The cost curve for DPP is also considered, with values detailed in Table 2.

Table 1. Economic Parameters of Each Components

Component	CAPEX	OPEX	REPEX	Lifetime
Diesel Power Plant (DPP)	0 (existing)	Cost curve Fuel: USD 0.69/L	Cost curve	30000 hours
Hydro Power Plant (HPP)	USD 2080/kW	USD 124,800/year	0	25 years
Biomass Power Plant (BPP)	USD 2000/kW (small) USD 1500/kW (large)	5% of CAPEX/year	0	25 years
Solar Power Plant (SPP)	USD 1253.7/kWp	USD 10/kWp	0	25 years
Gas-Fired Power Plant (GFPP)	USD 690/kW	10% of CAPEX/year Fuel: USD 0.142/m^3	USD 600/kW	60000 hours
Battery Energy Storage System (BESS)	USD 866.92/kWh	USD 693.54/kWh	80% of CAPEX	10 years
Power Conversion System (PCS)	USD 420	0	0	25 years

Table 2. Cost Curve of DPP

Capacity	CAPEX	REPEX	O & M ($/op.hr)
50	0	30000	2.50
100	0	50000	4.30
200	0	88000	8.00
400	0	150000	15.00

3.2 Optimization Results of Namlea, Moko, Namrole and Wamsisi Interconnection System

The configuration of the system can be seen in Figure 7, while Table 3 shows a comparison of LCOE, renewable energy penetration, the amount of CO_2 emissions produced, and the reduction of CoE for each scenario.

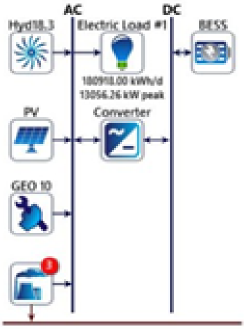

Figure 7. The Configuration of the Namlea, Namrole, Mako and Wamsisi Interconnection System

Table 3. Comparison of Optimization Scenario for Namlea, Namrole, Mako and Wamsisi Interconnection System

Scenario	Power Plant	LCOE (cUSD/kWh)	Reduction of CoE (cUSD/kWh)	Renewable Energy	CO_2 Emission (kg/year)
1	100% DPP	29.5	0	0	57.298,99
2	HPP 18.3 MW + BESS 6.317 MWh	9.33	20.17	100%	0
3	GFPP 8.73 MW + SPP 5 MW + BESS 9.17 MWh	8.28	21.22	79%	26.040,89

Based on HOMER optimization for the Namlea, Namrole, Mako and Wamsisi interconnection system, the optimal power generation system configuration is Scenario 2, which is a combination of 18 MW hydropower and BESS with 100% renewable energy penetration, which does not produce CO_2 emissions, and is able to reduce the system's CoE by 20.17 cUSD/kWh. The energy production and demand curves for the selected power plant system configuration can be seen in Figure 8 and Figure 9. The hydro power plant supplies the load throughout the day, while the lack of energy production from the hydro power plant in the night will be supplied from the BESS.

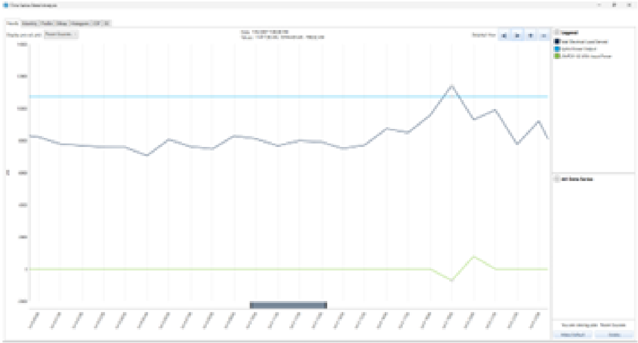

Figure 8. Daily Energy Production and Demand Curves for the Selected System Configuration

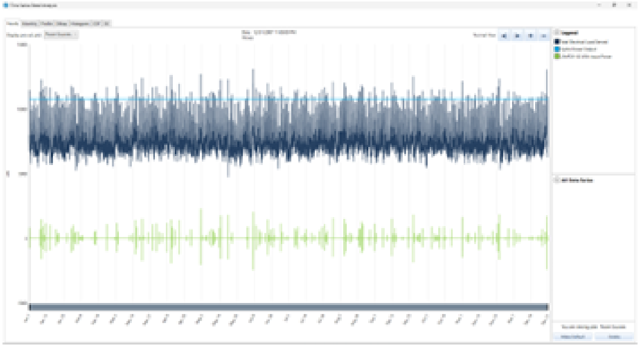

Figure 9. Annual Energy Production and Demand Curves for the Selected System Configuration

3.3 Optimization Results of Air Buaya System

The configuration of the system can be seen in Figure 10, while Table 4 shows a comparison of LCOE, renewable energy penetration, the amount of CO_2 emissions produced, and the reduction of CoE for each scenario.

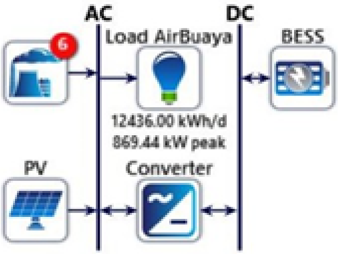

Figure 10. The Configuration of the Air Buaya System

Based on HOMER optimization for the Air Buaya system, the optimal configuration of the electricity generation system is Scenario 3, namely a combination of 600

Table 4. Comparison of Optimization Scenario for Air Buaya System

Scenario	Power Plant	LCOE (cUSD/kWh)	Reduction of CoE (cUSD/kWh)	Renewable Energy	CO_2 Emission (kg/year)
1	100% DPP	29.9	0%	0	57,298.99
2	BPP 200 kW + SPP 5.5 MW + BESS 17.429 MWh	55.6	-25.7	100%	417
3	DPP 600 kW + BPP 200 kW + SPP 2.896 MW + BESS 3.086 MWh	2.66	3.3	84%	941,918

kW DPP, 200 kW BPP, 2.896 MW SPP, and 3.086 MWh BESS. This configuration results in 84% of renewable energy penetration, 941,918 kg/year of CO_2 emissions produced, and able to reduce the system's CoE by 3.3 cUSD/kWh. The energy production and demand curves for the selected power plant system configuration can be seen in Figure 11 and Figure 12. The SPP supplies the load during the day, and at night the load will be supplied from the BPP, DPP and BESS.

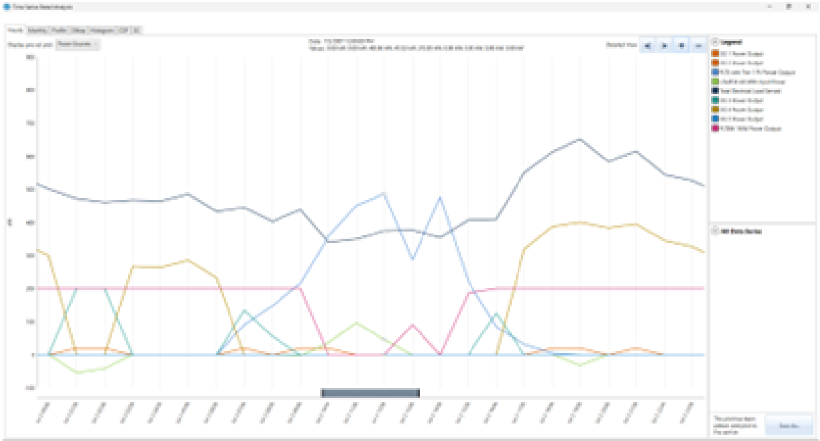

Figure 11. Daily Energy Production and Demand Curves for the Selected System Configuration

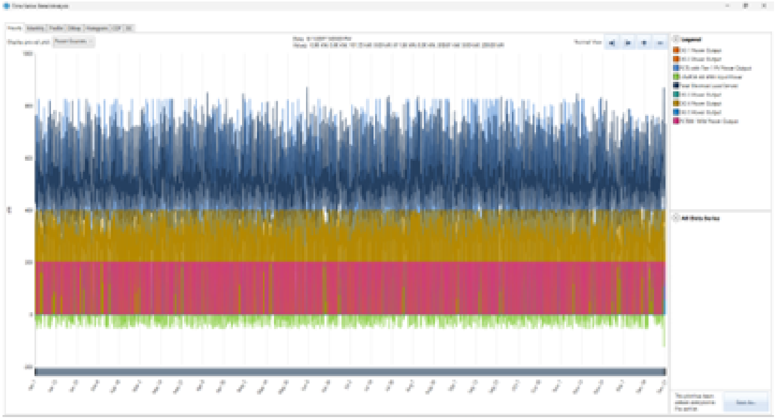

Figure 12. Annual Energy Production and Demand Curves for the Selected System Configuration

3.4 *Optimization Results of Leksula System*

The configuration of the system can be seen in Figure 13, while Table 5 shows a comparison of LCOE, renewable energy penetration, the amount of CO_2 emissions produced, and the reduction of CoE for each scenario.

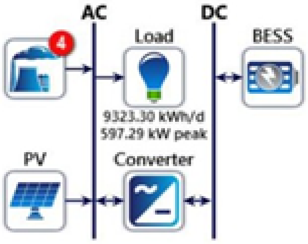

Figure 13. The Configuration of the Leksula System

Table 5. Comparison of Optimization Scenario for Leksula System

Scenario	Power Plant	LCOE (cUSD/kWh)	Reduction of CoE (cUSD/kWh)	Renewable Energy	CO_2 Emission (kg/year)
1	100% DPP	30.1	0	0%	2,846,477
2	SPP 7.5 MW + BESS 14.4 MWh	69.9	-39.8	100%	0
3	DPP 580 kW + SPP 979 kW + BESS 3.086 MWh	23.7	6.4	41.3%	1,852,083

Based on HOMER optimization for the Leksula system, the optimal configuration of the electricity generation system is Scenario 3, namely a combination of 580 kW DPP, 979 kW SPP, and BESS of 3.086 MWh. This configuration results in 41.3% of renewable energy penetration, 1,852,083 kg/year of CO_2 emissions produced, and able to reduce the system's CoE by 6.4 cUSD/kWh. The energy production and demand curves for the selected power plant system configuration can be seen in Figure 14 and Figure 15. The SPP supplies the load during the day, while at night the load will be supplied from the DPP and BESS.

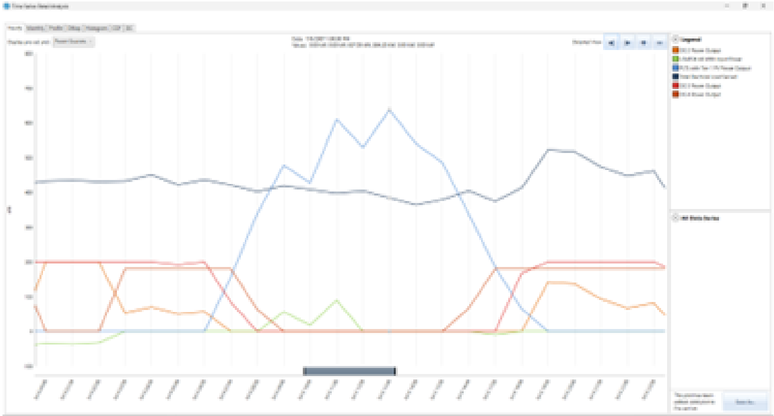

Figure 14. Daily Energy Production and Demand Curves for the Selected System Configuration

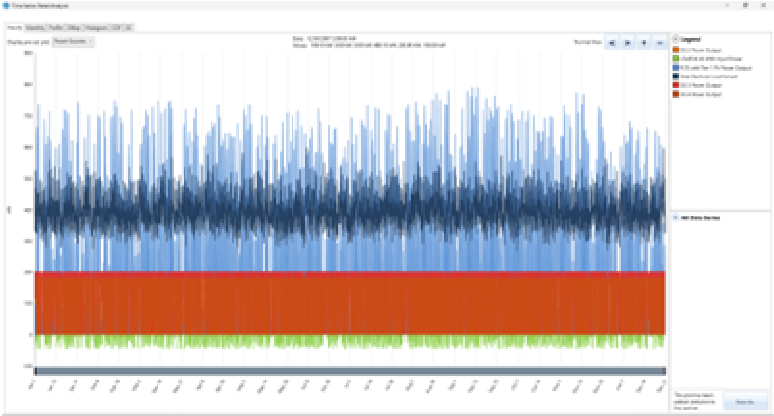

Figure 15. Annual Energy Production and Demand Curves for the Selected System Configuration

3.5 Optimization Results of Waipandan System

The configuration of the system can be seen in Figure 16, while Table 6 shows a comparison of LCOE, renewable energy penetration, the amount of CO_2 emissions produced, and the reduction of CoE for each scenario.

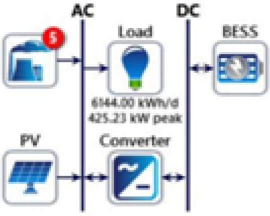

Figure 16. The Configuration of the Waipandan System

Table 6. Comparison of Optimization Scenario for Waipandan System

Scenario	Power Plant	LCOE (cUSD/kWh)	Reduction of CoE (cUSD/kWh)	Renewable Energy	CO_2 Emission (kg/year)
1	100% DPP	36.4	0	0%	1,933,626
2	SPP 6.05 MW + BESS 10.14 MWh	78.4	-42	100%	0
3	DPP 470 kW + SPP 727 kW + BESS 106 kWh	30.7	5.7	36.7%	1,372,659

Based on HOMER optimization for the Waipandan system, the optimal configuration of the electricity generation system is Scenario 3, namely a combination of 470 kW DPP, 727 kW SPP, and BESS of 106 kWh. This configuration results in 36.7% of renewable energy penetration, 1,372,659 kg/year of CO_2 emissions produced, and able to reduce the system's CoE by 5.7 cUSD/kWh. The energy production and demand curves for the selected power plant system configuration can be seen in Figure 17 and Figure 18. The SPP supplies the load during the day, while at night the load will be supplied from the DPP and BESS.

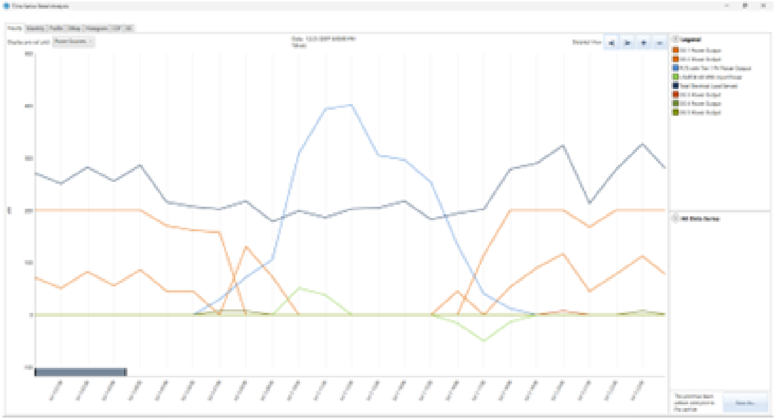

Figure 17. The Configuration of the Waipandan System

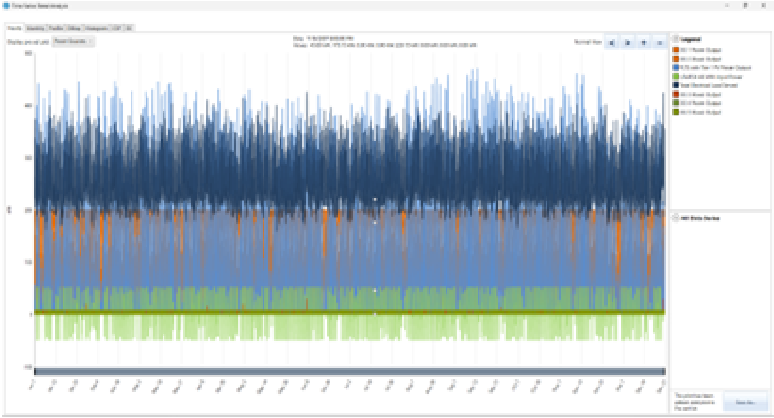

Figure 18. The Configuration of the Waipandan System

4. Conclusion

Optimization of renewable energy development on Buru Island is a solution to reduce system's CoE, reduce CO_2 emissions, and increase national energy security. Based on simulations and optimizations carried out for all 7 (seven) Buru Island electricity systems, the electricity system planning is simplified into 4 (four) systems, namely the Namlea, Moko, Namrole, Wamsisi interconnection system, the Air Buaya system, the Leksula system, and the Waipandan system.

For the integrated systems of Namlea, Moko, Namrole and Wamsisi, the configuration of the HPP and BESS were obtained, i.e. 18.3 MW and 6,317 kWh. The LCOE is 9.33 cUSD/kWh or a reduction of 20.17 cUSD/kWh from the existing LCOE with zero CO_2 emissions. For the Air Buaya system, the most optimum power plant configuration is a hybrid configuration between 600 kW DPP, 200 kW BPP, 2.896 MW SPP and a 3.086 MWh BESS. The LCOE for the Air Buaya system is

26.6 cUSD/kWh or a reduction of 3.3 cUSD/kWh from the existing LCOE. Furthermore, the renewable energy mix is 84% and the CO_2 emissions produced are 941,918 kg/year.

For the Leksula system, the most optimum power plant configuration is a hybrid configuration between 580 kW DPP, 979 kW SPP, and 3.086 MWh BESS. The LCOE for the Leksula system is 23.7 cUSD/kWh or is a reduction of 6.4 cUSD/kWh from the existing LCOE. The renewable energy mix is 41.3% and the emissions produced are 1,852,083 kg/year. While for the Waipandan system, the most optimum power plant configuration is also a hybrid configuration between 470 kW DPP, 979 kW SPP, and 3.086 MWh BESS. The LCOE is 30.7 cUSD/kWh or a reduction of 5.7 cUSD/kWh from the existing LCOE, with CO_2 emissions of 1.372.659 kg/year.

References

[1] Ministry of Energy and Mineral Resources. *Handbook of Energy & Economic Statistics of Indonesia 2023*. Ministry of Energy and Mineral Resources, 2023.

[2] Secretariat General of National Energy Council. *Outlook Energi Indonesia 2023*. Secretariat General of National Energy Council, 2023.

[3] Government of Indonesia. *Government Regulation of Republic of Indonesia No. 79/2014 regarding National Energy Policy*. Government of Indonesia. 2014.

[4] A. Shufian et al. "Optimized Performance and Economic Assessment for Hybrid Island Microgrid System Considering Uncertainties". In: *Technology and Economics of Smart Grids and Sustainable Energy* 7.1 (2022), pp. 1–21. DOI: 10.1007/s40866-022-00156-9.

[5] H. M. Al Ghaithi, G. P. Fotis, and V. Vita. "Techno-Economic Assessment of Hybrid Energy Off-Grid System - A Case Study for Masirah Island in Oman". In: *International Journal of Power and Energy Research* 1.2 (2017), pp. 1–10. DOI: 10.22606/ijper.2017.12003.

[6] S. Ali and C. M. Jang. "Optimum design of hybrid renewable energy system for sustainable energy supply to a remote Island". In: *Sustainability (Switzerland)* 12.3 (2020), p. 1280. DOI: 10.3390/su12031280.

[7] Z. Arifin, H. Hassan, and D. Alkano. "Optimal Sizing and Performance Assessment of a Hybrid Diesel and Photovoltaic with Battery Storage limited by a Take-or-Pay Contract of Power Purchase Agreement in Nusa Penida Island, Indonesia". In: *International Journal of Renewable Energy Research* 11.3 (2021), p. 12247. DOI: 10.20508/ijrer.v11i3.12247.

[8] M. Barbaro and R. Castro. "Design optimisation for a hybrid renewable microgrid: Application to the case of Faial Island, Azores archipelago". In: *Renewable Energy* 151 (2020), pp. 434–445. DOI: 10.1016/j.renene.2019.11.034.

[9] A. Fayaz Ahamed et al. "Optimization of Hybrid Microgrid of Renewable Energy Efficiency Using Homer Software". In: *International Journal of Renewable Energy Research* 11.4 (2021), pp. 234–248.

[10] W. He et al. "Optimal analysis of a hybrid renewable power system for a remote island". In: *Renewable Energy* 179 (2021), pp. 96–104. DOI: 10.1016/j.renene.2021.07.034.

[11] M. S. Hossain Lipu et al. "Design Optimization and Sensitivity Analysis of Hybrid Renewable Energy Systems: A case of Saint Martin Island in Bangladesh". In: *International Journal of Renewable Energy Research* 7.2 (2017), pp. 234–246.

[12] S. Muhammad et al. "Application of Dynamic Programming for Optimal Hybrid Energy Management System: Hydro-Photovoltaic-Diesel-BESS". In: *IEEE Access* 11 (2023), pp. 73767–73781. DOI: 10.1109/ACCESS.2023.3296699.

[13] I. Padrón et al. "Assessment of Hybrid Renewable Energy Systems to supplied energy to Autonomous Desalination Systems in two islands of the Canary Archipelago". In: *Renewable and Sustainable Energy Reviews* 101 (2019), pp. 221–230. DOI: 10.1016/j.rser.2018.11.009.

[14] O. O. Akinte et al. “Energy Storage Management of a Solar Photovoltaic–Biomass Hybrid Power System”. In: *Energies* 16.13 (2023), p. 5122. DOI: 10.3390/en16135122.