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Optimization of Solar Photovoltaic-Based Microgrid for Sustainable Energy Planning in Bajoe Port, Bone Regency, South Sulawesi: A Case Study

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ABSTRACT

Electrification in rural areas is still inadequate due to the limitations of the main power grid. Therefore, harnessing available renewable energy sources, such as solar energy, is an appropriate solution. The solar photovoltaic (PV) system can be utilized either in connection with the main power grid or in standalone mode (islanded) and can be supported by other power generation sources through a microgrid approach to enhance reliability. This research focuses on the design of a power system backed by a single renewable energy source, based on Photovoltaic (PV) technology, for the administrative building and passenger waiting area of Bajoe Port in Bone Regency. The microgrid technology is applied to improve the reliability and continuity of the electricity supply. The limited power supply at the site will be addressed using a microgrid system that combines power from the main grid, PV modules, and emergency generators. The system modeling takes into account the sensitivity of global climate conditions and local load requirements. The HOMER Pro software is utilized as a simulator to optimize the designed system. The PV module, with an array area of 186.92 m^2, will be installed in the parking area of Bajoe Port, which covers an area of 3,264.3 m2. The best result for the PV system design within the microgrid system, with a capacity of 41.5 kWp, yields an electricity output of 180,451 kWh per year based on the local average solar irradiation of 5.05 kWh/m2/day. The economic evaluation, expressed in terms of Net Present Cost (NPC) amounts to Rp. 421,251,000, with a Cost of Energy (COE) of 126.04/kWh. Moreover, the system can contribute 110,305 kWh/year to the main grid operated by the state-owned utility, Perusahaan Listrik Negara (PLN). Simulation results indicate that the designed PV microgrid system can contribute to the local daily electrical load, with a daily power requirement of 117.78 kWh and excess energy being sold to the PLN grid.

Keywords: *Rural electrification; microgrid; solar photovoltaic; renewable energy; Net Present Cost; Cost of Energy.*

INTRODUCTION

Over the past 140 years, electrical energy has transformed human civilization into the modern era. This form of energy has revolutionized the way people communicate, learn, and transport themselves in their daily lives. Electricity is a crucial form of energy in the modern era, nowadays all of the modern technologies rely on the electricity to operate (Bryce, 2020). The availability of power is so critical for every country on the planet. Furthermore, the pressing issue of global warming, which is a critical topic of discussion, highlights the fact that current electricity generation heavily relies on conventional power plants fueled by coal, oil, and gas. These fossil fuels contribute to carbon dioxide (CO2) emissions, which accelerate global warming. Given the increasing electricity consumption in Indonesia each year, the excavation and burning of fossil fuels will become more extensive to meet the growing electricity demand (Dewi Puspa, 2012).

Renewable energy technologies, the most prevalent of which are photovoltaic (PV) modules, commonly known as solar panels, are one means of generating power. PV systems are intended to capture solar energy and produce a electricity through solar power plant. The unrealized potential for establishing a solar power plant with a microgrid system exists at Bajoe Port. The parking lot at the port, which currently lacks shade structures, can be utilized for this purpose. In addition to the technical potential, another aspect to consider for implementing a microgrid system at Bajoe Port is the lack of reliable electricity supply in Bone Regency, leading to frequent power outages in various districts. These outages have inevitable consequences for Bajoe Port, which serves as a public sea transportation hub and a docking area for local fishing vessels. Therefore, this research aims to leverage the available resources and reduce Bajoe Port's dependency on the local power grid by conducting technical and economic analysis to design a microgrid system at the port.

Since renewable energy sources such as solar power are intermittent at certain times, PV modules, which are the main components of the PV systems cannot generate electricity at night. Therefore, integration with other sources such as the PLN (state-owned utility) grid, energy storage systems, and backup generators (gensets) is necessary. The integration of these system configurations is commonly referred to as a microgrid. The concept of the microgrid was first developed by R. H. Lasseter in 2004 (Lasseter & Paigi, 2004). A microgrid can serve as an intelligent power grid, often called a "smart microgrid," which enables energy management and provides user interfaces to control and regulate it. By definition, a microgrid is a localized group of electrical sources and loads that operate interconnectedly, acting as a controlled unit that can synchronize with the centralized grid or function independently (Wang et al., 2011).

RESEARCH METHOD

In this study, a photovoltaic-based microgrid was designed for the Bajoe Port located in Bone Regency, South Sulawesi. The purpose of this microgrid planning is to reduce the electricity consumption cost and enhance the reliability of the electricity from the dependency on the main grid. Two types of data will be used in this study which are primary data and secondary data. The primary data taken from the Bajoe Port, then the secondary data will be provided by the credible resource from the web. The research methodology for designing a solar photovoltaic-based microgrid for reliable electrification at Bajoe Port, Bone Regency, South Sulawesi can be described as follows:

A. Area Analysis

The electrical infrastructure and energy demands of Bajoe Port were assessed to understand the specific requirements and challenges of the site. Bajoe Port which coordinates 4°32.8'S, 120°24.3'E. the climatic condition of Bone Regency has a tropical climate that is divided into two seasons, the rainy season and the dry season. Normal conditions for the dry season occur in the month of September to December(F Moh Alfan, 2021).

Figure 1. Bajoe Port, Bone Regency, South Sulawesi

Source: *https://www.google.com/maps*

As for the local solar irradiation sensitivity and temperature data based on data taken from Desktop software(Ganoe et al., 2014), *RETScreen* this software is an analyst application that analyzes the function of energy supplies in the actual performance conditions of building facilities, gives projected targets for efficiency improvements, and checks the development of buildings when they have been simulated is seen in Table 1 Local climate state data consisting of solar irradiation and local earth temperature provided by *RETScreen Expert*s software.

Table 1. . Solar Irradiance and Area Temperature in Bajoe Port

Climatic Circumstances		
Month	**Irradiation kWh/m²/d**	**Earth temperature (°C)**
January	4.81	27.0
February	4.85	26.9
March	5.11	27.3
April	4.91	27.5
May	4.61	27.3
June	4.38	26.7
July	4.54	26.5
August	5.36	27.2
September	6.01	28.4
October	5.90	29.3
November	5.36	29.0
December	4.77	27.6
Average	**5.05**	**27.6**

***Source:** (RETscreen Expert Desktop)*

The data will be used as input for technical calculations of solar power plants and simulations that will be carried out on HOMER *Pro*. As seen in Table 1, the average solar irradiation is 5.05 kWh/m^2/d then the local temperature has an average of 27.6 ^{o}C.

B. Technical Design

There were various steps to the design process. To begin, a load assessment was carried out to evaluate the port's electricity consumption trends and needs. Solar resource evaluation was then performed to analyze the availability of solar energy in the area. Based on these factors, the sizing and configuration of the PV system were determined. Integration with the main power grid and the specification of backup generators were also considered to ensure a reliable power supply.

There are several steps to designing PV systems as follows:

1. Determining Energy Generated from PV Module

The technical design of the PV module races on the consumption of electrical energy and the area of application of the module at the bajoe port, from the results of the study, data collection of daily electrical energy use is generated in a month. Furthermore, taking into consideration system losses, the predicted power losses are 30% (Ramdahani, 2018). Then the effective area of the module of the magnitude of the energy to be generated can be determined by the following equation (El-Shafy & Nafeh, 2009):

$$PV\ Area = \frac{E_L}{G_{av} \times \eta PV \times TCF \times \eta out} \qquad (1)$$

Where:

E_L = The amount of energy generated

G_{av} = Average Solar Intensity per day

TCF = Temperature Correction Factor

ηPV = Module Efficiency

ηout =Battery Efficiency x Inverter Efficiency

The temperature correction factor needs to be considered to find out the power magnitude of the PV module when the temperature increase occurs every 1 C^{o} (Dedisukma et al., 2015) with the following equation:

$$P't^{0}C = 0,5/t^{0}C \; x \; P_{Mpp} \; x \; increase \; t \; ^{0}C (2)$$

$$TCF = \frac{P_{Mpp \; at \; increasing} \; t^{0}C}{P_{Mpp}} \quad (3)$$

To find out the peak of the energy to be generated can be determined by Equation (4) assuming a *Peak Solar Insolation* (PSI) of 1000 W/m:

$$PV \; Peak \; Power = PVarea \times PSI \times \eta Pv (4$$

The number of PV module units required from the amount of electrical energy to be generated can't be determined by the following equation:

$$Module \; Needed = \frac{PV \; Peak \; Power}{Module \; Capacity} \quad (5)$$

2. Determining Battery Capacity

In determining the capacity of the battery, it is necessary to pay attention to how many days of autonomy is needed when the absence of the sun shines on that day, to determine the capacity of the battery can be determined using the following equation (Mahmoud & Ibrik, 2006):

$$C_{ah} = \frac{E_L \; x \; N}{V_B \; x \; DoD \; x \; \eta B} \quad (6)$$

$$C_{wh} = C_{ah} \; x \; V_B \quad (7)$$

The configuration of the battery that will later be in series and parallel to get the required system voltage of 220 V can be determined using the following equation:

Battery:

$$in \; series = \frac{System \; Voltage \; (V_B)}{Battery \; Voltage} \quad (8)$$

$$in \; parralel = \frac{Demand \; Capacity}{Battery \; Capacity} \quad (9)$$

3. Inverter Capacity *Design*

In determining the capacity of the *Inverter,* it is necessary to know the amount of power generated by the PV module in each array. due to the safety needs and feasibility of operating PV modules on each array, it is necessary to pay attention to the *safety factor* (Burdick Joseph & Schmidt Philip, 2018) so that the system runs well, therefore the capacity of the inverter can be known by doing calculations with equation (10) as follows:

$$lnventer \; Size = P_{Mpp} \; Array \times 1.25 \quad (10)$$

C. *HOMER Pro* Software Simulation

To conduct technical and economic analysis, this study used Homer Pro software to simulate a microgrid system to be planned at Bajoe Port, Bone Regency, South Sulawesi. HOMER Pro is a global standard software from HOMER Energy that functions to simulate microgrid design optimization from various sectors of use, ranging from designing rural electrical energy needs, islands, and military headquarters, and interconnecting the power grid with local power plants. This software was first developed by the National Renewable Energy Laboratory (NREL), and developed and distributed by HOMER Energy, HOMER (Hybrid Optimization Model for Multiple Energy Resources) has core capabilities provided in its software namely Simulation, Optimization, and sensitivity analysis. In the Homer Pro simulation, a decent simulation of all possible combinations of generating equipment that have been entered on the HOMER Pro from hundreds or even thousands of system simulations is carried out. While optimization, referring to the simulation that HOMER Pro has carried out will provide a decent sequence of system combinations so that the best combination of systems can be known from a technical and economic point of view. Sensitivity is an optional option that can provide models of various variables that affect the system to be designed such as wind speed, and fuel costs so that the optimal system of these variables can be known. Using HOMER Pro software will make comparing the best system configurations in one simulation trial easier. This can provide the best system configuration data based on the top order of simulation results.

D. Performance Evaluation

The performance of the optimized PV microgrid system was assessed. The energy output and system efficiency were analyzed to ensure that the system meets the electricity demands of Bajoe Port and provides a reliable power supply.

Through this research methodology, the study aimed to design an optimized solar photovoltaic-based microgrid system that would address the limitations of the main power grid and ensure an uninterrupted electricity supply at Bajoe Port. The economic analysis provided insights into the project’s financial feasibility, and the performance evaluation verified the system's capability to meet the energy needs of the port. Overall, the research contributes to regional energy resilience and promotes the utilization of renewable energy for sustainable electrification.

RESULT AND DISCUSSION

The source of electrical energy that will meet the electricity load of Bajoe Port is produced from 3 sources: the source of PV modules as the main base that will meet the load in the microgrid system, the main source of the state electricity network, namely from the State Electricity Company (PLN) as an exchange (*export-import)* of electrical energy so that there can be achieve export and import between the microgrid system network and PLN. Other components such as batteries, inverters, and emergency generators that were available before this planning were also used to support this microgrid system.

A. Technical Design of Solar Power Plant System

The following procedures can be taken to achieve the technical design of the solar power plant:

1. Determine Energy generated by PV Module

The technical design of the PV module races on the consumption of electrical energy and the area of application of the module at the bajoe crossing port, from the results of the study, the data collection of daily electrical energy use in a month was 117.78 kW / day, the average use during the day was 74.54 kWh and 43.24 kWh at night. Then the electrical energy to be generated is 117.78 x 130% = 153.114 kWh considering the system's losses during the day and night.

Figure 1. Bajoe Port Daily Load Profile

Source: *Author Via HOMER Pro Software*

Any temperature increases on the module ranging from 1 ^{o}C to 27.6 ^{o}C the average temperature of the Bajoe Port location will experience a decrease in output power by 0.5%. This temperature increase is racing against the average temperature of the Bajoe Port earth obtained from the *RETscreen Expert* platform of 7.2 ^{o}C, from the calculation results with the equations (2) and (3) of power at the time of each temperature increase of 14.94 W, so the maximum power output of the module to be used using a module with a power magnitude of 415 Wp is 400.6 Wp with a temperature correction factor of 0.965. If it is 20.4%, is 95%, and the average daily solar intensity is 5.05 kWh/m^{2}/d, using Equation (1) then the effective area of the module is 186,92 m^{2}.

The max power generated by the PV module with a module efficiency of 20.4 percent is 38,131.68 W. According to the calculation results of Equation (5), the modules required are as many as 91.2 units of PV modules to meet roof design approaches and to meet the voltage of the load system, the parallel-series module configuration must be considered, so the PV modules will be assembled 10 series and 2 parallels consisting of 5 module arrays, for a total module unit count of 100 PV modules. The array of modules is seen in Figure 2.

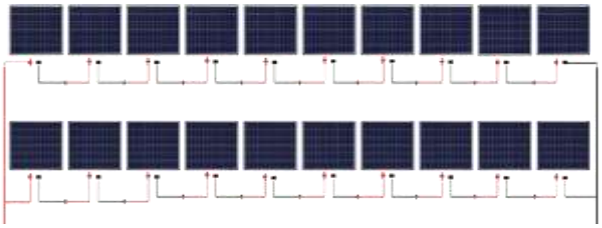

Figure 2. PV Module Array Circuit

Source: *Author*

Figure 3. Battery System Circuit

Source: *Author*

2. Microgrid Battery Capacity

The ampere-hour capacity (and watt-hour capacity) of the battery bank is critical for reserving the load demand based on the demands (number of days of autonomy) in the absence of sunshine. The intended battery must be a lead acid type with a battery system voltage of 220 V and a battery efficiency of 97.60 percent, while for *DoD* it is expected to be 80 percent, producing 483,18 ah.

The battery capacity required in this microgrid planning is 483.18 ah and will be fixed to 500 ah Battery configuration which will later be in series and parallel to get a voltage of 220 V Would be configured in 18 series and 5 parallel. It can be seen that the results found after performing calculations with Equations (8) and (9) are known that the battery to be used will be assembled in 18 series and 5 parallels. The wiring diagram can be seen in Figure 3. And the number of battery packs that will be used in the design of this microgrid is 18 x 5 = 90 batteries.

3. Microgrid Inverter Capacity

In determining the capacity of the *inverter*, it is necessary to know the amount of power generated by the PV module in each array, from the results of the planned array power calculation, each array to be applied at the bajoe port is 8,302.8 Watts. due to the safety and feasibility of operating PV modules on each array, it is necessary to pay attention to the *safety factor* (Burdick Joseph & Schmidt Philip, 2018) In order for the system to run well, therefore the capacity of the inverter can be known by performing calculations with equation (10) the output is 10.378,5 W. The inverter that will be used in the design of this study is to use the *Deye* brand inverter model *SUN-12K-SG01LP1-EU.*

4. Amount of Initial Microgrid Investment

To find out the initial investment cost of a microgrid, it is necessary to know the price of the equipment and the price of the components needed in the microgrid *design.* The cost of components and equipment that will be planned in this study is shown in Table 2.

Table 2. Initials of Investment Cost of Microgrids

Cost of equipment		
Component	**Price/unit**	**Total**
Risen PV Module 415 W (100 units)	IDR 2. 400. 000	IDR 230. 400. 000
Deye Hybrid Inverter 15 kW (5 Units)	IDR 44. 000. 000	IDR 220. 000. 000
Luminous Deep Cycle VRLA Battery 100 Ah 12 V (90 Units)	IDR 2,350,000	IDR 235. 000. 000
Chint DDSU666 Meter (5Units)	IDR 494. 000	RP 2. 470. 000
Roof Rail Mounting (96 Units)	IDR 165. 000	IDR 15. 840. 000
MCB Schneider 60ch 25A 2P (10 Units)	IDR 450. 000	Rp. 4. 500.0 00
MCB Schneider C120N 100A 3P (15 Units)	IDR 1. 313. 899	IDR 19. 708. 485
Panel Combiner (5 Units)	Rp. 1. 200. 000	IDR 6. 000. 000
TOTAL		IDR 686. 918. 485

Source: *https://www.tokopedia.com*

The initial investment cost is not included with the cost of the generator, because in this design the generator set is available at Bajoe Port, therefore the generator will later be considered in terms of operating costs *(Operational Cost)*.

B. Microgrid Configuration Design

The microgrid system that will be planned at Bajoe Port will be implemented microgrid electrical system as shown in Figure 7 which consists of PV arrays, Hybrid Inverters, batteries, generators, and electricity sources from PLN.

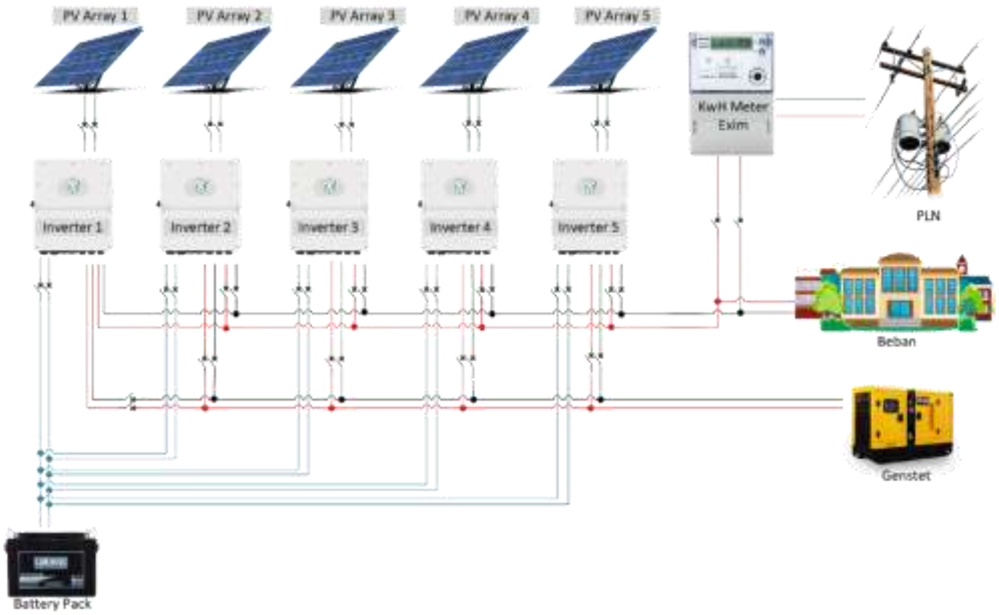

Figure 4. Wiring Diagram of Microgrid

Source: *Author*

The planned source of electrical energy from the administrative office building and passenger waiting room comes from PLN electricity sources which have an installed power of 70 kVA, 5 PV module arrays consisting of 100 module units with a capacity of 415 watts, generators with a capacity of 100 kVA, and Valve Regulated Lead Acid Batteries which have a capacity of 500 Ah consisting of 90 battery units assembled with 5 parallels and 20 series.

Energy management will be applied to the Bajoe Port microgrid which later this scheme will be run by 5 units of *15 kW Deye Hybrid Inverters* connected in parallel with the Master-slave control method where the source of electrical energy to be distributed to the load is connected to the AC / DC bus through the inverter on the microgrid. Of the 5 inverter units that will be applied to the microgrid, one of them will be used as a master (Nshuti, 2022) inverter and the other will be connected as a slave. The inverter that acts as the master is an inverter that acts as a controller of the integrity of the microgrid system.

C. HOMER Pro Software Simulation Results

The system configuration can be seen from the simulation view of the *HOMER Pro* software in Figure 5.

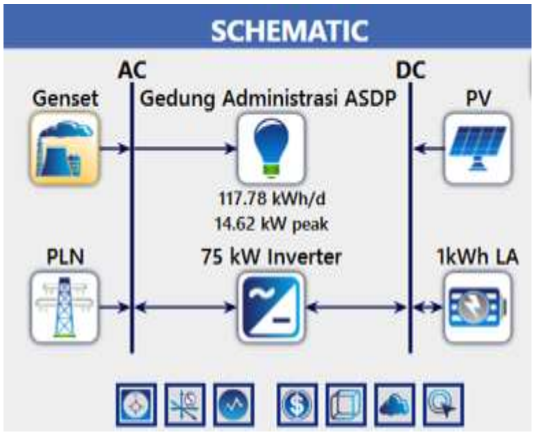

Figure 5. Microgrid System Configuration in Bajoe Port

Source: *Autor Via HOMER Pro Software*

Each microgrid component shown in Figure 5, has its own system cost in each component. System costs are covered in *HOMER Pro* software which consists of the initial investment cost of equipment, operating costs, and equipment maintenance *(Operational & Maintenance Costs)*. This cost variable will eventually be used to identify the optimum configuration outcomes from the simulation. Operating and maintenance costs refer to a year's cycle, in each year the costs required based on the calculation of the *National Renewable Energy Laboratory* (NREL) are 0.5% for large-scale systems and 1% for small-scale systems(Walker, 2017).

Therefore, the high cost of operating and maintaining the microgrid used in this planning is 1% of the total initial investment of the microgrid system. The microgrid system consists of 3 sources, from the results of the simulation, there are 2 best configurations that have the lowest NPC value out of 586 simulation results. Table 3 shows the input parameters of the system cost aspect before the simulation results are carried out. Because the system will later be connected to the main electricity network (PLN), it is assumed that the selling price of the exported electricity will be priced based on the reference (Prima Martha, 2022), which is Rp.868.

Table 3. Input Parameters of Microgrid Economic Aspect in HOMER Pro Software

SYSTEM COST (Rp)				
Components	**Capital**	**Replacement**	**O&M**	**Total**
PV Module	230.400.000	184.320.000	2.304.000	417.024.000
Emergency Generator Set	0	80.000.000	1.251.784.800	1.331.784.800
Battery	235.000.000	188.000.000	2.350.000	425.350.000
Inverter	220.000.000	176.000.000	2.200.000	398.200.000
System	685.400.000	628.320.000	1.258.638.800	2.572.358.800

Source: *Author*

1. Optimization Result of PV Module System and PLN Power Grid

The first configuration simulation result is with the configuration of the PV Module system and the PLN Electricity Network where the result of this configuration, the PV module produces 143,401 kWh/year and the amount of electricity purchased from PLN's electricity network is 16,583 kWh / year, as for the consumption data generated from this simulation, load consumption is 42,990 kWh/year and the electrical energy sold to PLN's power grid is 124,269 kWh/year. The total electrical energy produced in this configuration system is 159,985 kWh / year where the production of electrical energy produced is dominated by PV modules, namely with a percentage of 89.6% of the total electrical energy production.

Figure 6. Optimization Result of Configuration 1

Source: *Author Via HOMER Pro Software*

The PV module, which serves as the basis for electrical energy production from microgrid planning, will work for 4,380 hours/year Factor capacity *(capacity factor*) of 15.9%, and in this configuration, the module produces electricity from the light of 449 kWh / day From the results of the simulation the cost of configuring this system for 25 years as shown figure 6.

From *HOMER Pro* simulation results, investment costs *(capital)* of PV modules have the highest cost because PV modules require 100 units which are relied on as the main electrical energy supply base at the Bajoe Port load. In operating costs, PV modules have the highest operating costs due to the large operating costs and maintenance of modules, so they consume the highest operating costs of all equipment in the system. For replacement costs (*Replacement Cost*), the inverter has the highest cost because it has been known that the inverter requires a change of equipment when the efficiency in converting electrical energy decreases, therefore the inverter will be replaced every 15 years. As a result of the simulation of configuration 1 with a combination of the PV Module system and the PLN Power Network, the NPC (*Net Present Cost*) is Rp. 421,251,000, and the average electricity price per kWh (*Levelized Cost of Energy*) is Rp. 126.04/kWh.

2. Optimization Result of PV Module System, Battery, and PLN Power Grid

The second arrangement comprises of the PV module system, batteries, and PLN electrical network in which power is produced. In the PV module, electrical energy of 143,401 kWh/year is produced, electrical energy from PLN's electricity network is 16,583 kWh/year, then in the load section of electrical energy consumption in this second system configuration consumes electrical energy of 42.990 kWh/year in buildings, and sales of electrical energy to the PLN network are 123. 994 kWh/year.The total energy produced by the system is 159, 985 kWh/ year where in this optimization result the dominating source of electrical energy is the PV Module with a combination of batteries that have a percentage of 89.6% of the entire system. The simulation results are shown in Figure 11.

Production	kWh/yr	%
Generic flat plate PV	143,401	89.6
Grid Purchases	16,583	10.4
Total	159,985	100

Consumption	kWh/yr	%
AC Primary Load	42,990	28.0
DC Primary Load	0	0
Grid Sales	110,305	72.0
Total	153,295	100

Quantity	kWh/yr	%
Excess Electricity	3,316	2.07
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	89.2
Max. Renew. Penetration	166

Figure 7. Electrical Production of Configuration 2

***Source:** Author Via HOMER Pro Software*

This combination system has additional batteries that affect the NPC value greater than from the first system combination. If we review the reliability, this system will be more reliable than the first system because it has a battery that is used as a backup when PV modules and PLN electricity supply are not available at night.

The combination system consisting of PV modules, batteries, and PLN electricity networks produces an average electrical energy price or *cost of energy* (COE) of Rp. 158.13 /kWh and NPC of Rp. 528,446,800 over the project life time span of 25 years.

3. Combination of Generator System and PLN Electricity Network

The initial situation before the planned *PV* module-based microgrid. In the simulation results of the combination of the Generator system and the PLN Electricity Network, it was produced that the production of electrical energy for loads was all generated from the PLN electricity network and the generator set did not operate at all, this was because the generator at Bajoe Port was only used for emergency situations when there was no supply of electrical energy from the PLN power grid.

Production	kWh/yr	%
Genset Darurat	0	0
Grid Purchases	42,990	100
Total	42,990	100

Consumption	kWh/yr	%
AC Primary Load	42,990	100
DC Primary Load	0	0
Total	42,990	100

Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	0
Max. Renew. Penetration	0

Figure 8. Electricity Production Combination of PLN Electricity Network System and Emergency Generator

Source: *Author Via HOMER Pro Software*

CONCLUSION

This study analyzes technically and economically the design of microgrids in the port area to utilize parking spaces and also improve electrical reliability in public facilities at low costs. From the results of the study, there are 2 sources of electrical energy available at Bajoe Port, namely the PLN electricity network and emergency generators. Therefore, from this planning, a simulation experiment of *HOMER Pro* software was conducted to find out the technical and economic aspects of the microgrid system to be designed. The simulation results produced the 2 best configurations, taking into account reliability and cost, these configurations consist of PV modules and PLN electricity networks which produce a lower *Net Present Cost* (NPC) of Rp. 421,251,000, in this system combination producing electricity of 159,985 kWh / year which is dominated by electricity produced by PV modules, namely with a percentage of 90.9% with a Cost *of Energy* (COE) of Rp. 126.04/kWh.

The combination of PV module systems, batteries, and PLN electricity networks produces a slightly higher NPC, Rp. 528,446,800 this is because the addition of batteries to the system in the combination of systems in generating electricity requires a cost of Rp. 158.13 / kWh. Of the 2 configurations, it can contribute to PLN's electricity network of 110,305 kWh / year. The results show that the battery can effectively replace the generator's function as an emergency electrical supply at a lower cost.

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