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Techno-economic assessment of Bilacenge PV grid system in Southwest Sumba

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Abstract

A solar photovoltaic (PV) grid system with an energy management system (EMS) has been installed in Bilacenge, Southwest Sumba. This 400 kWp PV-Grid system is the first system in Indonesia that can control the electricity output to the grid. It comprises two battery blocks that support the system in maximizing electricity generation. This study has been conducted to evaluate the installed PV-grid system with EMS compared to diesel generators commonly used in remote areas. The study employs various techno-economic methods, including life cycle cost (LCC), levelized cost of energy (LCoE), and economic feasibility analysis based on several parameters such as net present value (NPV), payback period (PBP), and benefit-cost ratio (BCR). The results show that the system will experience a return on investment after operating for 34 years, accompanied by a BCR value of 0.60, which indicates that the investment of this PV grid system is not economically profitable.

Keywords: benefit-cost ratio (BCR); energy management system (EMS); levelized cost of energy (LCoE); life cycle cost (LCC); net present value (NPV); payback period (PBP).

I. Introduction

The Indonesian government has issued Government Regulation No. 79 of 2014 concerning the National Energy Policy regarding the progressive increase of renewable energy in the energy mix. The regulation sets targets for the utilization of renewable energy to reach 23 % of the primary energy mix by 2025 and 31 % by 2050. This regulation aims to guide the management of national energy toward achieving independence and resilience in the energy sector to support the sustainability of national development [1]. Based on the Net Zero Emission target, Indonesia is undertaking an ambitious energy transition, aiming to achieve full decarbonization by 2060, with a focus on developing 421 GW of solar energy capacity [2]. One of the endlessly renewable energy sources is sunlight, which can be harnessed as a source of PV grid. Indonesia has a substantial solar energy potential, estimated at 200,000 MW. Yet its utilization remains very small, at around 0.08 %, or approximately 150

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MW [3]. Presidential Regulation No. 22 of 2017 on the General Plan for National Energy (RUEN) projects a total PV grid capacity of 6.5 GW by 2025 and 45 GW by 2050, representing 22 % of the solar potential [4]. To enhance the reliability of electricity services and the adequacy of electricity supply, a PV grid system with energy storage provides a solution [5].

The PV grid-EMS (energy management system) installed in Bilacenge, Southwest Sumba, is the result of revitalizing an existing PV system constructed in 2011. In 2017, PT Kyudenko (Kyushu Electrical Company) of Japan added EMS technology to this renewal. The installation of the EMS aims to maximize the use of stored energy [6][7][8]. This makes it the first PV system in Indonesia to be equipped with EMS technology, allowing constant control of the electrical power output to the State Electricity Company (PLN) electricity grid [9]. The PV grid systems in small and remote islands have the potential to improve energy access, decrease costs, and enhance quality [10]. The PV grid in Southwest Sumba Regency initially consisted of the a-Si/μc-Si PV subsystem with a capacity of 500 kWp, smart generators (2x135 kVA), a vanadium redox battery (VRB) (2x240 kWh), and a control and data communication subsystem built in 2011–2012 [11]. Over time, some components of the PV system experienced damage. The VRB batteries and some inverter units did not function properly, leading to the revitalization of the PV system in 2017 with assistance from the Japanese government. PT Kyudenko, a Japanese company, contributed technology to revitalize this PV grid-connected system by adding an EMS subsystem. Currently, EMS technology has a great role in achieving the best performance with the highest benefits [12][13][14] optimizing battery utilization [15], selling locally produced electricity to the utility network [16], as well as strengths in the areas of flexibility, controllability, and strategic energy planning [17][18].

The 400 kWp PV grid system with EMS offers advantages such as regulating the timing and quantity of electricity fed into the grid. Equipped with a 1,152 kWh battery bank, it delivers 200 kW for 7–8 hours during the dry season and up to 6 hours in the rainy season, depending on stored energy. This ensures reliable power quality and enables the PV array to maximize energy generation. The battery bank stores excess daytime PV generation for redistribution to the grid as needed [9]. The PV power plant systems also include 16 PV converter units of 25 kW each and 6 DC/AC inverter units of 50 kW each. The EMS is supported by the smart meter controller (SMC), battery monitoring unit (BMU), and smart power management (SPM). The PV grid system also utilizes supervisory control and data acquisition (SCADA) for remote real-time monitoring [19]. The EMS organizes the PV grid system into two-block symmetrical subsystems, ensuring equal components, specifications, and power capacity. It regulates the electrical output of both subsystems to the grid, maintaining constant total power at a specific rate and interval. The EMS settings dictate that each subsystem generates between 65 % and 35 % of the total power supplied to the grid, with daily alterations based on the availability of energy in each subsystem's battery bank [9].

To optimize the energy generated by the PV grid-EMS in Bilacenge, a techno-economic analysis of the system is needed to determine the electricity generation cost and the feasibility of the PV grid-EMS Bilacenge system. This calculation aims to determine the cost of generating electricity from the PV grid-EMS Bilacenge and assess the feasibility of the EMS technology applied to the PV system. Similar techno-economic studies have been conducted in previous research to assess the feasibility of various PV systems. Previous studies have analyzed the techno-economics of rooftop PV systems for residential customers in Spain [20], Australia [21], and Indonesia [22][23].

Techno-economic studies were also conducted for public facility buildings PV systems, such as company buildings [24][25], university buildings [26][27][28], and a hospital [29]. Several studies of techno-economic for community energy sharing [30], agriculture farms [31], and prediction studies [32][33] have also looked at the viability of centralized PV systems. Software like HOMER [34][35] and PVSyst [36] have been used to compare the techno-economic aspects of hybrid PV systems with other generation systems. Other studies also analyze the cost of EMS for microgrids [15] and hybrid power systems [37].

This study conducted analysis using several economic methods, namely life cycle cost (LCC) and levelized cost of energy (LCoE), as well as economic feasibility parameters, including net present value (NPV), payback period (PBP), and benefit-cost ratio (BCR).

II. Materials and Methods

This study has conducted a techno-economic assessment of the PV grid-EMS in Bilacenge, Sumba. The operating principle of the PV grid-EMS system can be seen in Figure 1. The methodology employed in this research includes several analysis methods: the LCC method, the LCoE, and economic feasibility studies. Various analysis methods are used to assess the feasibility across various techno-economic parameters.

A. Life cycle cost

LCC is the total accumulation of initial investment, operation costs, maintenance costs, component replacement costs, salvage value, and resale value [38]. The LCC value can be calculated using equation (1) [38].

$$\mathrm{LCC} = \mathrm{CAPEX} + \sum_{t=1}^{t=n}\frac{\mathrm{OPEX}_t}{(1+i)^t} + C_{\mathrm{replacement}}^{\mathrm{total}} - V_{\mathrm{residual}} \quad (1)$$

where LCC is the life cycle cost, present value, CAPEX is the capital expenditure, OPEX is the operational expenditure discounted with i over the project lifetime n, $C_{\mathrm{replacement}}^{\mathrm{total}}$ is the component replacement cost, and $V_{residual}$ is the residual value at the end of the project.

B. Net present value

NPV is a method of calculating the net value at present using the discounted cash flow (DCF) technique to account for the time value of money in all project cash flows [28]. This method compares the present value of total net cash inflows with the total present value of investments. The NPV is calculated using equation (2), as follow.

$$\mathrm{NPV} = \sum_{t=1}^{n}\frac{\mathrm{NCF}_t}{(1-i)^t} - I \quad (2)$$

where NCF_t is the total net cash flow from year 1 to year n, I is the initial investment, i is the interest, and n is the lifetime.

The NPV value determines the feasibility or infeasibility criteria for this method under the following circumstances:

- $\mathrm{NPV} > 0$ means the investment is deemed feasible or profitable.
- $\mathrm{NPV} < 0$ means the investment is deemed infeasible or unprofitable.
- $\mathrm{NPV} = 0$ means the investment neither gains nor loses.

C. Levelized cost of energy

LCoE is a standard tool for comparing the costs of various electricity generation technologies. LCoE measures the total cost and electricity produced by a power generation system over its operational lifetime. LCoE is selected as one of the primary metrics for evaluating system viability because it is a widely recognized and fundamental indicator that allows for the comparison of different power generation technologies [39]. Typically, the timeframe is determined based on the lifetime of the generation system [40]. The LCoE is calculated using equation (3), as shown below.

$$\mathrm{LCoE} = \frac{\sum_{t=0}^{n}\frac{\mathrm{Total\ cost}_t}{(1+d)^t}}{\sum_{t=0}^{n}\frac{\mathrm{PV\ generation}_t}{(1+d)^t}} \quad (3)$$

where LCoE is the investment cost of the power plant in year t, $\mathrm{Total\ cost}_t$ is the total cost of the power plant in year t, d is the discount rate, and $\mathrm{PV\ generation}_t$ is the electricity generation produced (in kWh) in year t.

D. Payback period

PBP is the time required for the investor to recover the investment. A PBP calculation is performed to assess the financial risk of the upcoming project. A smaller PBP is considered better, indicating a quicker return on investment and lower financial risk [41]. PBP

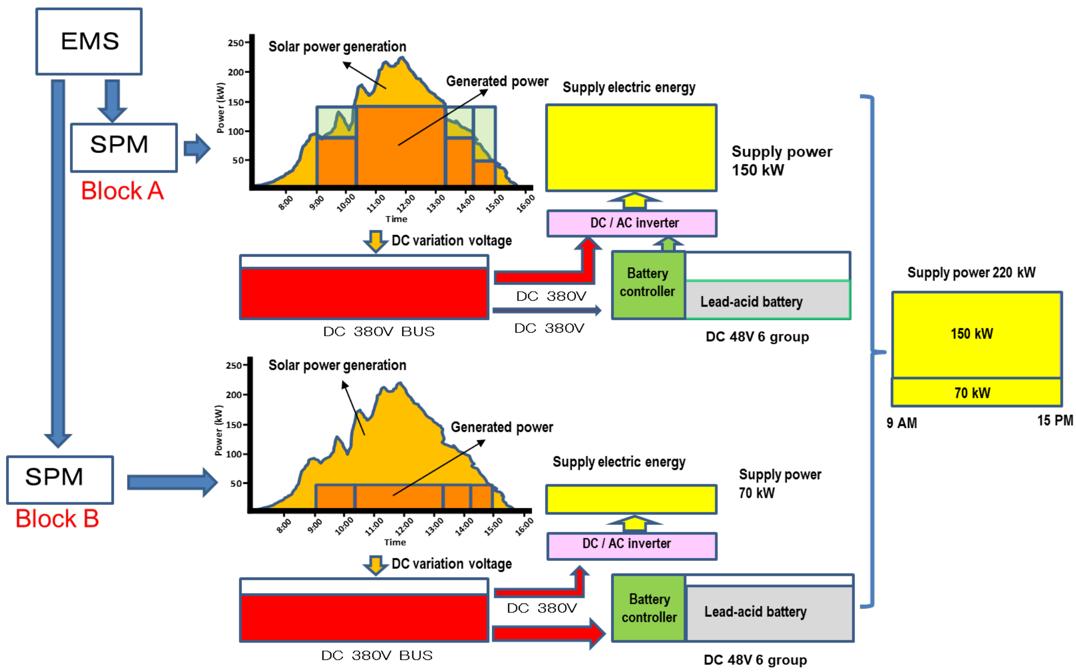

Figure 1. Operating principle of the EMS in the PV grid system at Bilacenge.

can be analyzed using the NPV curve or by employing equation (4) [41].

$$PBP = \frac{IC}{NCF} \quad (4)$$

where IC is investment cost, while NCF, or net cash flow, is the net cash during the year, NCF is the value of electricity sales minus operating and maintenance costs (M) during one year. An investment is feasible if PBP $< n$ or the PBP is less than the project's lifespan (n). The further below the project's lifespan, the greater the potential profit of a project. If PBP $> n$, the investment is deemed infeasible.

E. Benefit-cost ratio

The BCR is the percentage value of the power generation system compared to the initial investment cost and operational and maintenance costs [28]. The BCR is formulated using equation (5).

$$BCR = \frac{\text{Benefit}(B)}{\text{Cost}(C)} \quad (5)$$

The decision criteria to determine whether an investment plan is economically feasible or not using this method are as follows:

- BCR > 1, the investment is deemed feasible.
- BCR < 1, the investment is deemed unfeasible.

III. Results and Discussions

This section discusses the calculation and analysis of the technological and economic aspects of the PV grid-EMS microgrid system in Bilacenge, which serves as a pilot project for implementing new technology and systems for assessment and application purposes. The analysis parameters include energy production projections, LCC, NPV, PBP, and BCR. This study's limitations do not consider the overall economic considerations of the electricity system in the Southwest Sumba region, considering the integrated impact of the PV grid-EMS Bilacenge into the grid.

A. Projection of energy production

The energy production generated during the operational period is projected based on the energy production data in 2018, which is the first year of PV grid operation. The reference energy production data shown in Figure 2 is used for project energy production in the coming years. In this study, the production or operational lifespan of the PV grid-EMS Bilacenge system is assumed to be up to 20 years. Based on the production data in 2018, the projected values of PV grid-EMS energy production from 2019 to 2037 have been obtained. The projections assume a 0.5 % annual decrease in energy production [42]. The projected energy production data during the lifespan period is presented in Figure 3.

Based on the calculation, the total energy production from PV grid-EMS over 20 years is 9,042,926 kWh. According to Regulation of the Ministry of Energy and Mineral Resources of the Republic of Indonesia (Kementerian ESDM) No. 19 of 2016, the purchase price of electricity from the PV grid by PLN for the East Nusa Tenggara region is valued at 23.0 USD/kWh. Then, in 2022, Presidential Regulation No. 112 of 2022 was issued, which regulates the purchase price of electricity from renewable energy sources. According to Presidential Regulation No. 112 of 2022, the purchase price of electricity or feed-in tariff (FiT) from photovoltaic (PV) solar power plants whose land is provided by the government (excluding battery facilities or other electricity storage facilities) for

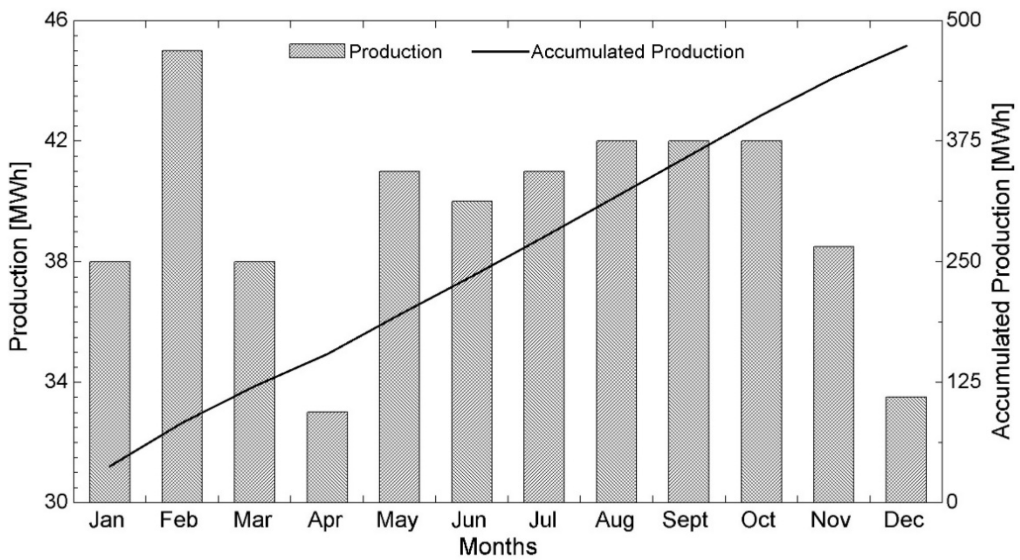

Figure 2. Energy production of PV grid-EMS in 2018.

capacities up to 1 MW in the East Nusa Tenggara region is 13.076 USD/kWh for years 1 to 10, and then 6.536 USD/kWh for years 11 to a maximum of 30. Then, the battery facility will add a reference price of up to 60 % of the electricity purchase price so that the total purchase price for electricity and battery facilities is 20.92 USD/kWh for years 1 to 10 and then 10.458 USD/kWh for years 11 to a maximum of 30.

In 2019, the dollar's exchange rate against the rupiah was Rp14,481. Thus, the price of PV grid electricity is valued at Rp3,331/kWh. Projected electricity prices during the lifespan period are revealed in Figure 3. The annual revenue, after taking into account the FiT regulatory and projected energy production, is depicted in Figure 4. Exchange rate data for 2018–2022 is real data obtained from Central Agency of Statistics (BPS) [43], while exchange rate data for 2023–2037 is a prediction with linear regression based on real exchange rate data for 2000–2022. The total revenue from the sale of PV grid-EMS electricity during the operation period is Rp23,333,528,042.

B. Life cycle cost

LCC represents the expenses incurred for developing a PV grid until its operation and maintenance (O&M) [38]. The investment costs considered in this research are for a 400 kW PV grid system with EMS technology. The cost components in this study are divided into initial investment costs and O&M costs [44]. The investment costs are further divided into hard costs for the purchase of components and soft costs for payments of services required in constructing the PV grid and obtaining permits [45]. In this study, hard costs include the subsystem costs of PV, batteries, and inverters [46]. Meanwhile, soft costs encompass development, engineering, permitting, and commissioning expenses [47]. Soft cost items

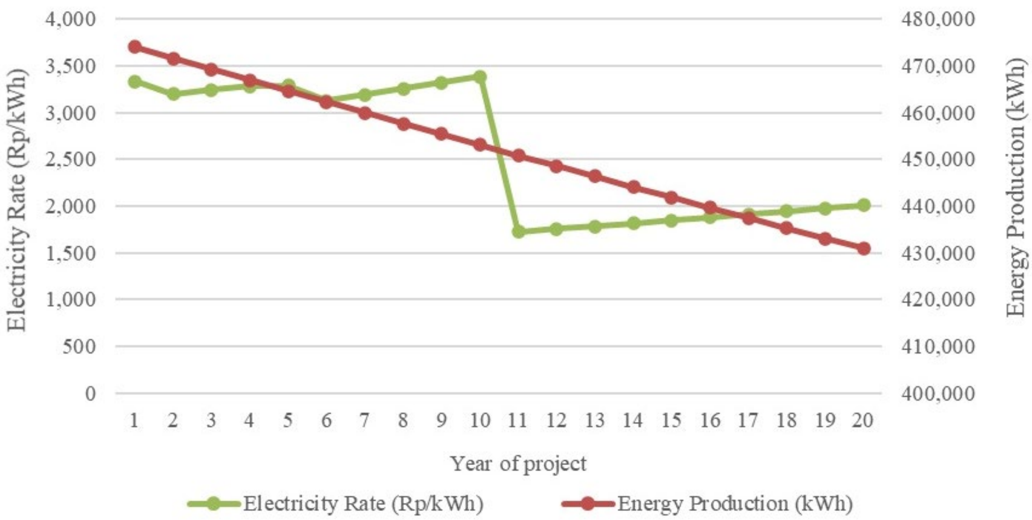

Figure 3. Projection of energy production and electricity rate in 20 years lifetime project.

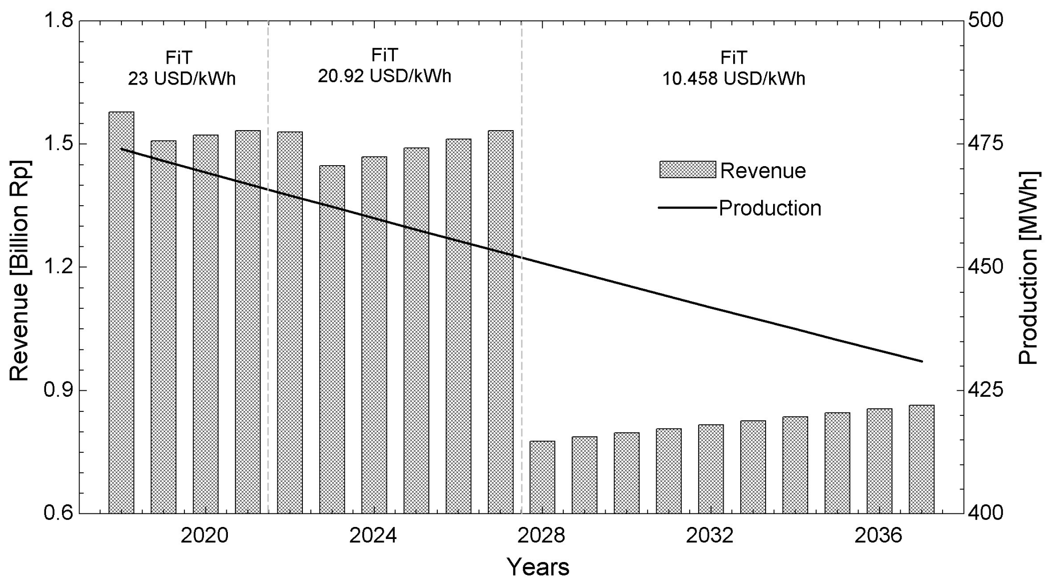

Figure 4. Projection of annual revenue based on projected electricity production of the PV grid-EMS in Bilacenge.

calculated in this study include developer cost, engineering, permitting, and commissioning. The budget cost of each item is presented in Table 1. The detailed purchase prices for each hard cost and soft cost component are depicted in Figure 5 that shows that hard cost contributes 87.24 % of total investment costs. Meanwhile, soft costs contribute 12.76 %. The investment cost is mostly used for PV modules and their components, which require 42.47 % of the total investment cost. The calculation results in a total investment cost of about Rp38,663,104,289.

During its lifespan or operational period, a PV grid requires O&M costs encompassing several components. The calculation of O&M costs in the first year of PV grid operation is assumed, as shown in Figure 6. The O&M cost comprises several cost items, namely site maintenance, cable inspection, panel washing, vegetation, and inverter maintenance and replacement. Each of them has a specific budget, as represented in Table 1 [48]. The total O&M costs shown in Figure 6 represent the O&M costs for one year in 2018, which is the total cost at Rp71,400,000. Therefore, the O&M costs of the PV grid-EMS system in the 2nd to 20th years require further calculations. Assuming that the factors influencing O&M costs are only inflation from Bank Indonesia [49][50][51], the calculation of O&M costs over the lifespan is presented in Figure 7. The calculation of O&M costs during the operation period results in a total value of Rp1,504,172,297. The LCC cost is the total investment and O&M cost; thus, the LCC cost for the PV grid-EMS system is Rp38,663,104,289.

C. Levelized cost of electricity

LCoE can be determined by using equation (3). Based on the LCC analysis and energy production that has been calculated before, the LCoE from PV grid-EMS is defined as Rp4,276/kWh. This value is higher than the purchase price of electricity from PV solar power plants (land category provided by the government) based on Presidential Regulation No. 112 of 2022. However, based on a survey on the PV grid-

Table 1.
Budget of soft-cost investment and O&M cost of a PV system.

Category	Cost Item	USD/kWh-year	USD/Watt
Soft-cost investment	Developer cost		0.15
	Engineering		0.50
	Permitting		0.09
	Commissioning		0.05
O&M	Site maintenance	0.2	
	Cable inspection	1.4	
	Panel washing	0.8	
	Vegetation	0.5	
	Inverter maintenance	3.0	
	Inverter replacement	6.0	
Total		11.9	0.79

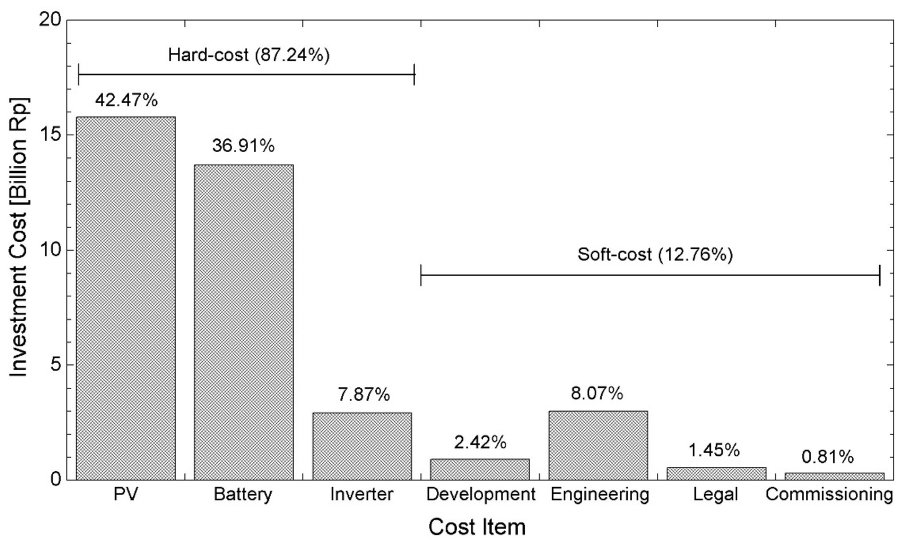

Figure 5. Investment cost of PV grid-EMS in Bilacenge.

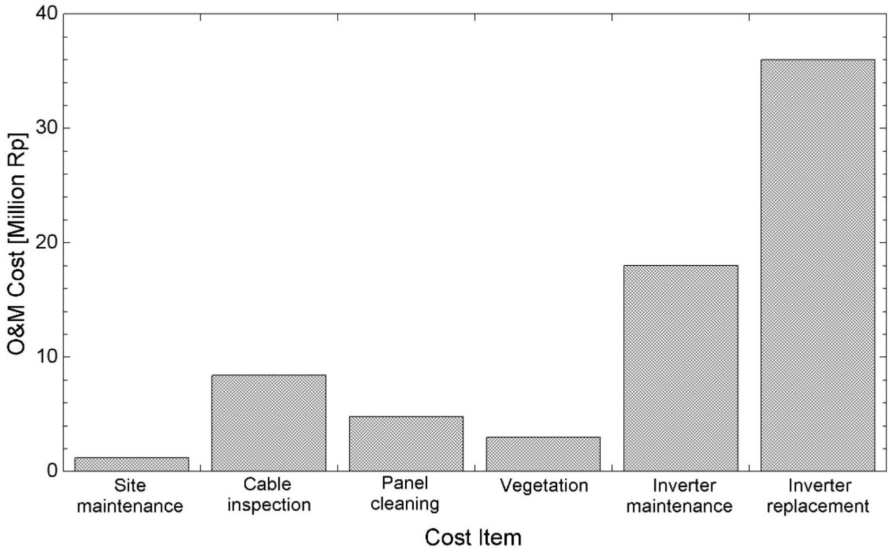

Figure 6. O&M cost of 400 kWp PV grid-EMS in 2018.

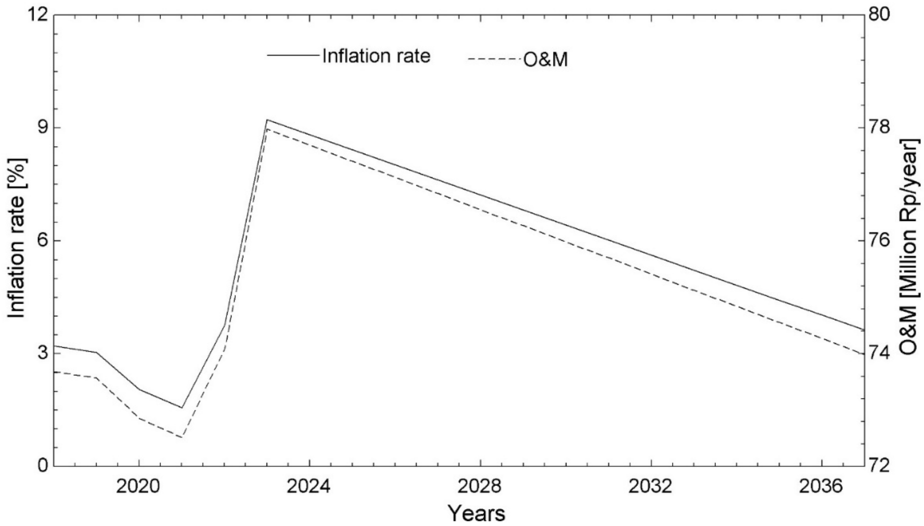

Figure 7. Yearly O&M cost of PV grid-EMS influenced by the inflation rate.

EMS Bilacenge site, PLN stated that the actual generation cost (BPP) in Southwest Sumba reached Rp4,500/kWh, where the predominant generators used are diesel generators. This indicates that using a PV grid in Southwest Sumba could reduce the local BPP and decrease diesel consumption.

D. Economic analysis

Economic analysis is conducted to determine the feasibility of the PV grid from an economic perspective. Several methods can be employed to conduct this economic analysis. In this study, economic analysis is performed using the NPV, PBP, and BCR methods.

1) Net present value

NPV calculation uses the formula in equation (2) with an annual interest rate of 6 % [52]. NPV is calculated based on cash inflows and outflows. Cash inflows represent the income obtained from the sale of electricity generated by the PV grid-EMS system and the salvage value, which is the selling value of the PV System components after their lifespan. Some references set the salvage value at 20 % of the investment value for a lifespan of 25 years [53][54]. Therefore, in this study, the salvage value is assumed to be 25 % of the investment value due to the shorter lifespan of 20 years. The NPV calculation shows a result of an NPV value amounting to Rp (-19,605,808,101.77). Regarding the value of NPV < 0, as a research-based plant that employs a two-block symmetrical subsystem to achieve a stable output throughout operational hours, this condition is deemed reasonable, considering the quantity and nominal values of the required devices, as it economically contributes to increasing the value of capital expenditures (CAPEX). In other words, for further study, it is necessary to examine the economy on a broader scale, specifically the macroeconomic aspects of network economics, focusing on the influence of a stable (non-intermittent) PV-microgrid output.

2) Payback period

The PBP method is used to predict the period of return on investment during the lifetime of the PV grid. PBP is calculated based on equation (4). The calculation gives results that the average annual net cash flow for PV Grid-EMS is Rp1,091,467,787, and the value of PBP is 34 years. The PBP value of PV Grid-EMS is greater than its lifespan, which is >20 years. As discussed before, this condition is deemed reasonable as a research-based plant, considering the quantity and nominal values of the required devices, as it economically contributes to increasing the value of CAPEX. So, this condition contributes to the extension of the PBP. For further study, it is necessary to examine the economy on a broader scale, specifically the macroeconomic aspects of network economics, focusing on the influence of a stable (non-intermittent) PV-microgrid output.

3) Benefit-cost ratio

BCR represents the comparison between benefits and costs. Benefits are the total income obtained during the system's lifespan, while costs are expenditures. In this case, costs include LCC or the total investment and the total of O&M. BCR analysis of the PV grid-EMS gives a result of a BCR value of 0.6. As described before, BCR value < 1; thus, the investment in the PV grid-EMS system is not yet beneficial as a research-based plant due to the introduction and development of novel technology and methods. It is necessary to examine the economy on a broader scale, focusing on the influence of a stable (non-intermittent) PV-microgrid output in further research.

IV. Conclusion

The techno-economic study of the Bilacenge PV Grid system in Southwest Sumba, conducted as a research-based plant, has yielded noteworthy results. The system demonstrates key characteristics, including a levelized cost of electricity (LCoE) value of Rp4,276/kWh, a negative NPV, a BCR of 0.60, and a PBP of approximately 34 years. Implementing a two-block symmetrical subsystem is instrumental in maintaining stable operational output, a condition deemed reasonable when considering the quantity and nominal values of the necessary devices. Nevertheless, the findings suggest further research to delve into the broader economic landscape, particularly exploring the macroeconomic facets of network economics. Focusing on the repercussions of a stable and non-intermittent PV grid output is crucial for comprehensively understanding the system's economic impact.

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Declarations

Author contribution

E. Nurdiana: Writing - Original Draft, Conceptualization, Formal analysis, Visualization. **M.V. Nugroho:** Writing - Review & Editing, Conceptualization, Investigation, Data Curation. **Z.A. Fikriyadi:** Resources, Software, Visualization. **F. Mardiansah:** Resources, Data Curation, Conceptualization. **D.V. Dianti:** Writing - Review & Editing, Formal analysis, Visualization. **D.M.P. Utami:** Conceptualization, Data Curation, Formal analysis. **K. Akhmad:** Supervision, Validation, Data Curation. **Y. Margowadi:** Writing - Review & Editing, Investigation. **A. Rezavidi:** Supervision, Validation, Data Curation.

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Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The use of AI or AI-assisted technologies

During the preparation of this work, the authors used **Grammarly** to proofread the manuscript and **Turnitin** was used for plagiarism-checking purposes. After using this tool/service, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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