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A Techno-Economic Study on the Planning of Solar Power Plant Upgrades Using the AHP Method on Neira Island, Central Maluku

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ABSTRACT

Maluku Province has significant solar energy potential; however, the utilization of the Solar Power Plant (Pembangkit Listrik Tenaga Surya [PLTS]) on Banda Neira Island has remained suboptimal because the facility, which was originally constructed in 2012, ceased operation in 2017. This condition has resulted in continued dependence on Diesel Power Plants (Pembangkit Listrik Tenaga Diesel [PLTD]), which contribute to high carbon emissions. This study aimed to determine the optimal rehabilitation scenario for the PLTS through a techno-economic assessment using the Analytical Hierarchy Process (AHP) method. Three hybrid PLTS configurations (PV+BESS+PLTD) were modeled using PVSyst and HOMER Pro software, with photovoltaic (PV) capacities of 360 kWp, 480 kWp, and 1,200 kWp, respectively. The optimal alternative was selected based on eight criteria: system reliability, facility complexity, fuel consumption reduction, capital expenditure (CAPEX), internal rate of return (IRR), levelized cost of energy (LCOE), carbon emission reduction, and land availability. The analysis showed that Scenario 2, consisting of a 480 kWp PV system integrated with a 1,610 kWh battery energy storage system (BESS), achieved the highest overall score. This scenario resulted in a performance ratio of 80.43%, an IRR of 19%, a return on investment (ROI) of 15.2%, and a payback period of less than five years. Furthermore, it reduced carbon emissions by approximately 530,469 kg CO_2 annually, representing a 9% reduction compared with the existing diesel-based system. These findings demonstrate that Scenario 2 provides the optimal balance among technical, economic, and environmental considerations, making it a recommended solution for hybrid solar power development in archipelagic regions and supporting Indonesia's transition toward renewable energy.

INTRODUCTION

As a member of the G20, Indonesia has ratified international agreements related to environmental protection, particularly those aimed at reducing carbon dioxide (CO_2) emissions. Indonesia has committed to reducing greenhouse gas emissions by 29% relative to the business-as-usual scenario by 2030, or by 41% with international assistance (RUKN 2019–2038). In response to global climate and energy challenges, many countries have increasingly shifted toward sustainable energy solutions. Solar photovoltaic (PV) systems have assumed a strategic role because of their substantial technical potential (Sianipar, 2017), efficient energy conversion, and relatively low greenhouse gas emissions during operation (Nugent & Sovacool, 2014).

With an average daily solar irradiation of approximately 4,500 Wh/m², Indonesia has considerable solar energy potential. Its equatorial location provides relatively consistent solar resources throughout the year, creating favorable conditions for the development of Solar Power Plants (Pembangkit Listrik Tenaga Surya [PLTS]) (Manahara et al., 2023) as an alternative source of electricity. Solar PV systems generate electricity by converting solar radiation directly into electrical energy through the photovoltaic effect (Bahramara et al., 2016). These favorable resource conditions strengthen the potential contribution of solar power to Indonesia's electricity supply and energy transition.

Indonesia's solar energy potential is substantial and relatively stable throughout the year, according to data from the National Energy Council (DEN) 2020. Solar energy can be utilized through solar thermal technologies for heating applications and photovoltaic technologies for electricity generation. Most regions of Indonesia have considerable potential for solar power development, with average solar irradiation of approximately 4 kWh/m^2 per day and relatively modest monthly variation. In western Indonesia, solar irradiation potential is approximately 4.5 kWh/m^2 per day with monthly variation of around 10%, whereas eastern Indonesia has higher potential of approximately 5.1 kWh/m^2 per day. Indonesia's overall technical solar energy potential has been estimated at approximately 207,898 MW (Bayu & Windarta, 2021).

The principal components of a solar PV system include PV modules, inverters, and, where energy storage is required, batteries. PV modules convert incoming solar radiation into electrical energy, while inverters convert direct current (DC) generated by the modules into alternating current (AC) suitable for electrical loads or grid connection. Battery energy storage systems (BESS) store excess electricity for use during periods of low or unavailable solar generation. Commercial PV modules are commonly based on monocrystalline or polycrystalline silicon technologies (Julianto et al., 2022), while emerging technologies such as dye-sensitized solar cells (DSSCs) continue to be developed. Advances in PV technology have progressively improved module efficiency and power density while contributing to reductions in solar generation costs (Lestari et al., 2021).

One of the Indonesian government's major energy policy objectives has been to increase the share of new and renewable energy in the national energy mix (Twidell & Weir, 2018). Solar energy has therefore become an increasingly important component of Indonesia's emissions reduction and electricity transition strategies. Energy transition scenarios developed by the IEA, IRENA, and IESR indicate that solar power could contribute a substantial share of national electricity generation under accelerated decarbonization pathways. However, the realization of planned solar PV capacity has continued to face implementation challenges. Only 12% (0.6 GWp) of the 4.7 GWp solar PV capacity planned under the 2021 Electricity Supply Business Plan (RUPTL) had entered the tender process. Distributed rooftop solar development was also constrained by regulatory and grid-capacity limitations despite the introduction of Minister of Energy and Mineral Resources Regulation No. 26/2021 concerning rooftop solar PV systems (Sofian et al., 2023).

National energy policies have established targets for increasing the contribution of new and renewable energy (NRE) to Indonesia's electricity system (Bhandari, 2018). These policies have encouraged the development of various renewable technologies, including micro-hydropower, biomass, wind power, and solar PV, as part of efforts to diversify the national energy mix and reduce dependence on fossil fuels (Faisal & Awaludin, 2022a). Among these technologies, solar PV has particularly strong potential because of Indonesia's geographic characteristics and widespread availability of solar resources (Agency, 2023b).

The installed capacity of solar PV systems in Indonesia was estimated at approximately 152.44 MW in 2020, of which about 10.9% consisted of rooftop solar PV systems, while the remainder primarily comprised ground-mounted installations. Several utility-scale and distributed solar PV projects have been developed across Indonesia, including the Likupang Solar Power Plant, with an installed capacity of approximately 21 MWp (Abed et al., 2025; Erdinc & Uzunoglu, 2012). Nevertheless, the utilized capacity remains relatively small compared with Indonesia's estimated solar energy potential of approximately 207.8 GWp (Agency, 2023a). Numerous smaller solar PV plants with capacities ranging from tens to hundreds of kilowatts peak have also been installed, indicating continued growth in solar PV deployment (Faisal & Awaludin, 2022b).

The increasing demand for electricity in eastern Indonesia, particularly on Banda Neira Island, requires reliable, efficient, and sustainable energy supply systems. As an internationally recognized tourism destination, Banda Neira requires stable electricity infrastructure to support economic activity and public services. However, the island's electricity system remains highly dependent on fossil fuel-based Diesel Power Plants (Pembangkit Listrik Tenaga Diesel [PLTD]). Fuel transportation to the island is also affected by maritime and weather conditions, resulting in relatively high operating costs and substantial carbon emissions. These conditions strengthen the need to develop hybrid renewable energy systems in which solar PV can reduce diesel fuel consumption while improving the sustainability of the island's electricity supply (Abed et al., 2025) .

This study aimed to determine the most appropriate scenario for upgrading the Solar Power Plant (Pembangkit Listrik Tenaga Surya [PLTS]) on Banda Neira Island through a techno-economic assessment that considered system reliability, facility complexity, fuel consumption reduction, capital expenditure (CAPEX), internal rate of return (IRR), levelized cost of energy (LCOE), carbon emission reduction, and land availability. The Analytical Hierarchy Process (AHP) was employed to identify the preferred alternative based on simulation results generated using PVSyst and HOMER Pro (Diaf et al., 2008). The analysis focused on the Banda Neira electricity system using 2026 load data and solar PV component specifications relevant to the Maluku region, with operational information obtained from PLTD Banda Neira and PLN UIW Maluku and North Maluku. The findings are expected to support decisions regarding appropriate solar PV capacity and rehabilitation strategies, contribute to renewable energy development, and provide a reference for hybrid solar PV deployment in archipelagic regions, particularly in eastern Indonesia.

METHOD

This study employed a quantitative approach consisting of literature review, data collection, system simulation, and optimization stages. The collected data included electricity load profiles, existing PLTD specifications, solar irradiation data, solar PV and Battery Energy Storage System (BESS) component specifications, and economic parameters such as investment costs, operation and maintenance costs, and diesel fuel prices. These data were used as the basis for modeling and analyzing the hybrid solar PV system on Banda Neira Island.

The next stage involved technical simulation using PVSyst software to estimate solar PV energy production under the research site conditions. The simulation results were subsequently used as input data for HOMER Pro to model and optimize various hybrid system configurations consisting of solar PV, BESS, and PLTD. Several alternative scenarios were generated and compared based on technical and economic indicators, including system reliability, investment costs, fuel consumption, energy costs, and carbon emission reduction.

To identify the most suitable alternative, the Analytical Hierarchy Process (AHP) method was applied. The assessment involved PLN experts who performed pairwise comparisons of eight criteria: system reliability, facility complexity, fuel consumption reduction, capital expenditure (CAPEX), internal rate of return (IRR), levelized cost of energy (LCOE), carbon emission reduction, and land availability. The criterion weights were calculated and evaluated using the consistency ratio (CR), which was then used to determine the most feasible hybrid solar PV scenario based on technical, economic, operational, and environmental considerations.

RESULTS AND DISCUSSION

AHP Analysis

The analysis of AHP in this study begins with a comprehensive literature review to ensure that the method used is relevant and feasible to be used as a multi-criteria decision selection. The AHP method is used to determine weights based on the assessment of experts so that it is able to provide data-based and accountable results. Thus, the basis of this literature can strengthen the decision to select the scenario of the repair of Hybrid Solar Power Plants on Banda Neira Island (Komiyama & Fujii, 2014).

This process began with a discussion with a team of experts who were directly related to the Banda Neira Island solar power plant improvement plan consisting of PLN UIW MMU, UP3 Ambon, ULP Banda and influential researchers to determine in the assessment of the AHP method.

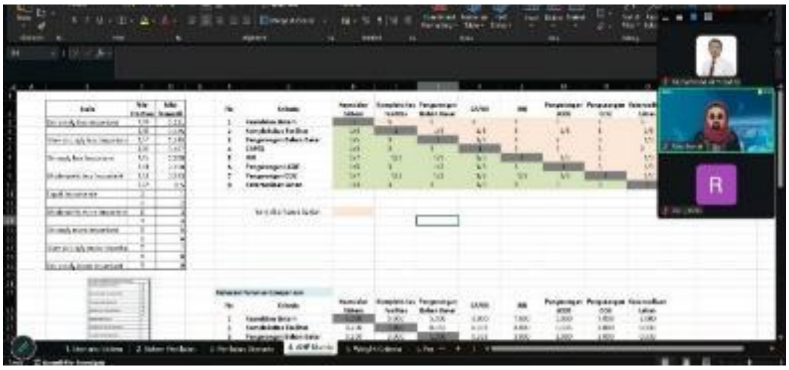

Figure 1. Discussions with relevant parties to discuss criteria and weights
Source: Research Team Documentation, 2026.

This result was obtained a pairwase comparison value on the AHP method to determine the weighting value.

Pairwise Comparison Matri

Table 1. Scoring Pairwise Comparison Matrix 9 Kriteria

1	5	5	3	7	5	7	3
1/5	1	1/3	1/3	3	1/3	3	1/3
1/5	3	1	1/3	3	2	3	1/3
1/3	3	3	1	5	3	5	3
1/7	1/3	1/3	1/5	1	1/3	2	1/3
1/5	3	1/2	1/3	3	1	3	1/3
1/7	1/3	1/3	1/5	1/2	1/3	1	1/3
1/3	3	3	1/3	3	3	3	1

Source: Primary Data, 2026.

In the AHP method, the process of determining the weight of the criteria is carried out through the preparation of a pairwise comparison matrix. This matrix is used to compare each criterion in pairs to assess the level of importance between criteria in the decision-making process. The data in the table above are the results of an assessment carried out jointly by experts, this assessment is carried out using a scale of 1 to 9 as developed by Thomas L. Saaty. When conducting this matrix assessment, experts fill in the value on the part marked in orange, while the value on the opposite side that is green is automatically calculated as the reciprocal value (Yang et al., 2009).

Table 2. Pairwise AHP Scale (Saaty, 1987)

Numerical Values	Description	Explanation
1	Equal importance of both elements	Two elements contribute equally
3	Moderate importance of one element over another	Experience and judgment favour one element over another
5	Strong importance of one element over another	An element is strongly favoured
7	Very importance of one element over another	An element is very strongly dominant
9	Extreme importance of one element over another	An element is favoured by at least one order of magnitude
2, 4, 6, 8	Intermediate values between two adjacent judgments	Used to compromise between two judgments

Source: Saaty (1980).

As described in the table above, in the AHP comparison scale, a value of 1 indicates that the two criteria have the same level of importance to the decision-making objectives. A value of 3 indicates that a criterion can be considered slightly more important than another, while a value of 5 indicates a stronger level of importance. A value of 7 is used on criteria that have a very strong degree of dominance, while a value of 9 indicates that one criterion is considered to have a very dominant or absolute degree of coolness compared to the other criteria. In addition, values such as 2, 4, 6 and 8 are used as compromise values to present judgments that fall between two adjacent levels of importance.

Based on the results of the pairwaise comparison, it can be seen that the System Reliability has a higher comparison compared to other criteria. This value shows that the reliability of the system is assessed as the dominant criterion which is shown in the row consisting of the number > 1 instead of 1/n. In addition to the Reliability of the System, there are other criteria that show a fairly high value, namely CAPEX and Land Availability. It can be concluded that these two criteria are quite important although they are not as dominant as System Reliability and have the potential to have a large final weight on the AHP results.

Thus, System Reliability is the first priority and followed by several assessments that have quite meaningful assessments afterwards. The following table is a calculation of the Pairwaise Comparison Matrix for further use in the Normalized Matrix.

Table 3. Pairwise Comparison Calculation

No.	Criteria	System Reliability	Facility Complexity	Fuel Consumption Reduction	CAPEX	IRR	LCOE Reduction	CO_2 Reduction	Land Availability
1	System Reliability	1.000							
2	Facility Complexity		1.000						
3	Fuel Consumption Reduction			1.000					
4	CAPEX				1.000				
5	IRR					1.000			
6	LCOE Reduction						1.000		
7	CO_2 Reduction							1.000	
8	Land Availability								1.000

Source: Primary Data, 2026.

Normalized Matrix

The following table shows the normalized matrix obtained from the normalization process of paired comparison matrix in the AHP method. This normalization process is carried out by dividing each value in the paired comparison matrix by the total number of values in the column in question. With this process, all the values in each column will have a proportion relative to the total of the columns so that they can be compared more objectively.

Table 4. Normalized Matrix

No	Criteria	System Reliability	Facility Complexity	Fuel Consumption Reduction	CAPEX	IRR	LCOE Reduction	CO2 Reduction	Land Availability	Weight
1	System Reliability	1.000								34.6 %

No	Criteria	System Reliability	Facility Complexity	Fuel Consumption Reduction	CAPEX	IRR	LCOE Reduction	CO2 Reduction	Land Availability	Weight
2	Facility Complexity		1.000							6.3%
3	Fuel Consumption Reduction			1.000						9.6%
4	CAPEX				1.000					20.2%
5	IRR					1.000				3.8%
6	LCOE Reduction						1.000			8.4%
7	CO2 Reduction							1.000		3.1%
8	Land Availability								1.000	13.9%
	Total									**100%**

Source: Primary Data, 2026.

This normalization matrix is used to describe the level of contribution of each criterion to the overall assessment which then the average value on each row of the normalization matrix can be calculated to obtain a priority vector or criterion weight. The weight represents the level of relative importance of each criterion and becomes the basis for the evaluation process and determination of each criterion and becomes the basis for the evaluation process.

Final Weight

Based on the results of the calculation of the normalization matrix, it can be seen that the reliability of the system obtained the highest weight with a value of 34.6%, showing that in the repair of the Neira Island solar power plant, the main consideration is that the reliability of the system is more important than other criteria.

Table 5. Criteria Weights

No	Criteria	Weight
1	System Reliability	34.6%
2	Facility Complexity	6.3%
3	Fuel Consumption Reduction	9.6%
4	CAPEX	20.2%
5	IRR	3.8%

No	Criteria	Weight
6	LCOE Reduction	8.4%
7	CO2 Reduction	3.1%
8	Land Availability	13.9%

Source: Primary Data, 2026.

In addition to the reliability of the system that has the highest weight, CAPEX and Land Availability also show a significant level of importance, at 20.2% and 13.9%, respectively. The high weight of CAPEX shows that initial investment needs are one of the main considerations in the decision-making process. This is in line with the condition of electricity infrastructure projects that are generally financed by the government, where the efficiency of the use of funds is an important factor. On the other hand, the availability of land is also an important criterion considering the geographical condition of Banda Neira which has limited area for the development of power generation facilities.

Consistency Check

Table 6. Consistency Check Calculation

No	Criteria	System Reliability	Facility Complexity	Fuel Consumption Reduction	CAPEX	IRR	LCOE Reduction	CO2 Reduction	Land Availability	Average	Eigen Value
1	System Reliability	0.135	0.017	0.036	0.105	0.011	0.028	0.008	0.048	0.049	7.120
2	Facility Complexity	0.027	0.005	0.002	0.012	0.005	0.002	0.003	0.005	0.007	8.429
3	Fuel Consumption Reduction	0.027	0.010	0.007	0.012	0.005	0.011	0.003	0.005	0.010	9.579
4	CAPEX	0.045	0.010	0.021	0.035	0.008	0.017	0.006	0.048	0.024	8.698
5	IRR	0.019	0.001	0.002	0.007	0.002	0.002	0.002	0.005	0.005	7.505
6	LCOE Reduction	0.027	0.010	0.004	0.012	0.005	0.005	0.003	0.005	0.009	9.348
7	CO2 Reduction	0.019	0.001	0.002	0.007	0.001	0.002	0.001	0.005	0.005	6.422
8	Land Availability	0.045	0.010	0.021	0.012	0.005	0.017	0.003	0.016	0.016	8.632
	Weight	**34.6%**	**6.3%**	**9.6%**	**20.2%**	**3.8%**	**8.4%**	**3.1%**	**13.9%**		

Source: Primary Data, 2026.

The table above is part of the Consistency Check process in the AHP method which aims to evaluate the level of consistency of the pairwise comparison assessment that has been carried out previously. In the table, each element on the row is the result of multiplication between the pairwise comparison matrix and the weight vector, which produces a Weighted Sum Vector (WSV) for each criterion. Next, each WSV value is divided by the weight of the associated criteria to obtain the λ (lambda) value of each criterion. The average of all λ values produces a λmax value (principal eigenvalue), eigenvalue indicates the overall consistency level of the paired comparison matrix, in the sense that the closer the λmax value is to the sum of criteria (n), the more consistent the assessment given. From the table it can be seen that the maximum value of λ is obtained as 8.190.

This max λ value will then be used to calculate the Consistency Index (CI) and Consistency Ratio (CR) in the next stage. CI is calculated using equation (14) in subchapter 2.2.6, where n is the sum of criteria (in this case 8). Meanwhile, CR is obtained by comparing CI with Random Index (RI) which is in accordance with the number of criteria.

Table 7. Consistency Check Results

Consistency Calculation	Value
λ maks	8.190
n [Number of Criteria]	8
C.I. [Consistency Index]	0.027140211
R.I. [Random Consistency Index]	1.41
CR [Consistency Ratio]	2%

Source: Primary Data, 2026.

The advanced table of the Consistency Check process shows the final step to evaluate the consistency of the paired comparison matrix in the AHP method. Based on the maximum eigenvalue (λ max) of 8.190, we can calculate the Consistency Index (CI) with the following criteria (14):

$CI = (\lambda\ max - n) / (n - 1)$

$CI = (8.190 - 8) / (8 - 1) = 0190 / 8 = 0.0271$

Furthermore, for the number of criteria as many as 9, the Random Index (RI) value according to the AHP table is 1.41. So:

$CR = CI / RI = 0.0271 / 1.41 \approx 0.0192$ or $1.92 \approx 2\%$

A Consistency Ratio (CR) value of 2%, or a CR value of < 0.1 (or < 10%) indicates that the consistency level of the pairwise comparison assessment is within acceptable limits, so the assessment results are considered logically consistent. This indicates that the preferences given between the criteria are quite stable and can be used as a valid basis for decision-making in the Repair of Solar Power Plants on Neira Island. Thus, the AHP process that has been carried out has met the necessary consistency requirements.

Analysis of the selection of the best scenarios

Based on the results of the AHP calculation, the final score of each scenario was obtained through a process of alternation between the scoring value of each criterion and the priority weight that had been determined by the expert team. The final score is then added up to obtain the total score of each scenario.

The calculation results showed that Scenario 2 obtained the highest total score of 4.44, followed by Scenario 1 of 3.56 and Scenario 3 of 3.38. Thus, Scenario 2 is determined as the best alternative based on the results of a multi-criteria evaluation using the AHP method.

The high value of Scenario 2 is influenced by its relatively balanced performance on various key criteria. This scenario obtained the highest scores on the aspects of system reliability, CAPEX, and land availability, which are some of the criteria with the greatest weight in the decision-making process. In addition, Scenario 2 also shows an increase in the use of solar energy and a better reduction in fuel consumption than Scenario 1, without requiring investment or land needs as much as Scenario 3.

Table 8. Final Outcome of Scenario Assessment

Criteria	Skenario 1			Skenario 2			Skenario 3		
	Value	**Weight**	**Final Score**	**Value**	**Weight**	**Final Score**	**Value**	**Weight**	**Final Score**
System Reliability	4	0,346	1,383	5	0,346	1,729	5	0,346	1,729
Facility Complexity	5	0,063	0,315	4	0,063	0,252	1	0,063	0,063
Fuel Reduction	2	0,096	0,193	3	0,096	0,289	5	0,096	0,482
CAPEX	4	0,202	0,808	5	0,202	1,010	1	0,202	0,202
IRR	2	0,038	0,077	3	0,038	0,115	5	0,038	0,192
LCOE Reduction	2	0,084	0,167	3	0,084	0,251	5	0,084	0,418
Reducing Carbon Emissions	2	0,031	0,063	3	0,031	0,094	5	0,031	0,157
Land Availability	4	0,139	0,558	5	0,139	0,697	1	0,139	0,139
	Total Final Score of Scenario 1		**3,56**	**Total Final Score of Scenario 2**		**4,4**	**Total Final Score of Scenario 3**		**3,4**

Source: Primary Data, 2026.

Meanwhile, Scenario 1 has advantages in terms of lower facility complexity and competitive investment needs, but the resulting technical benefits, such as fuel reduction, LCOE reduction, and carbon emission reduction, are still lower than Scenario 2. On the other hand, Scenario 3 provides the greatest technical and environmental benefits through an increase in the renewable energy fraction, a reduction in fuel consumption, a reduction in carbon emissions, and the most significant reduction in LCOE. However, the much higher investment requirements, increased complexity of facilities, and greater land requirements cause the total value to be lower after considering the weight of all criteria.

Based on these results, it can be concluded that Scenario 2 provides the best balance between technical, economic, operational, and implementation aspects, so that it was chosen as the most optimal scenario to be applied to the research site.

Detailed Analysis of Techno-Economic Best-Scenario

After evaluation using the AHP method, Scenario 2 with a configuration of 480 kWp PV and 1,610 kWh BESS was determined as the best alternative. In this subchapter, a more detailed analysis of the technical and economic performance of the selected scenario is carried out to provide a more comprehensive overview of system implementation.

Economic Analysis

Based on the results of cost estimates, the total initial investment in the Banda Neira Hybrid Solar Power Plant system with scenario 2 is IDR 16.69 billion. The largest investment component came from BESS with a value of IDR 7.87 billion or 47.15% of the total investment, followed by the Balance of System of IDR 3.92 billion or 23.51%, and PV modules of IDR 1.79 billion or 10.70%. The dominance of investment in BESS shows that energy storage systems are still the main factor affecting the cost of implementing hybrid systems.

Meanwhile, the BoS component includes various supporting equipment such as distribution panels, wiring systems, system monitoring and interfaces, grounding, and system protection needed to ensure system reliability. In addition, civil works and EPC & Commissioning together accounted for around 16.26% of the total investment, which includes foundation construction and mounting structures, engineering design, installation, and logistics. The composition of these costs shows that the investment of the system is not only determined by key components such as PV and batteries, but also by the needs of the supporting infrastructure and the overall implementation of the project.

Table 9. Percentage of Investment Cost Component

Cost Component	Value (Rp)	Percentage
PV Module	IDR 1,785,541,632	10,70%
Inverter	IDR 398,695,947	2,39%
BESS	IDR 7,869,343,003	47,15%
Balance of System (BoS)	IDR 3,924,781,665	23,51%
Civil Works	IDR 1,459,941,776	8,75%
EPC & Commissioning	IDR 1,253,015,603	7,51%

Source: Primary Data, 2026.

With the structure of the investment cost component above, the modeling results using HOMER Pro presented in table 4-12 subchapter 4.1 show that Scenario 2 can be declared economically feasible.

Scenario 2 has an NPC value of IDR 634.39 billion, which is lower than the existing basecase system that only uses generators, which shows that the total cost that must be incurred during the lifetime of the project can be reduced through the implementation of PV and BESS system integration. On the other hand, as discussed in the analysis subchapter of each scenario, the LCOE of scenario 2 is about 4% lower than the condition of only PLTD. Then, the IRR value of 19% shows that the rate of return on investment generated by this project can be at a fairly attractive level. This value shows that the economic benefits obtained from operating cost savings are able to provide a higher rate of return than the discount rate value used in the parameters or economic input data in the HOMER Pro software, which is 6.9%.

In terms of investment returns, the ROI value of 15.2% also shows that the amount of investment spent is able to generate positive economic benefits during the operating period. Meanwhile, the value of the payback period shows that the value of the initial investment can be returned in less than five years.

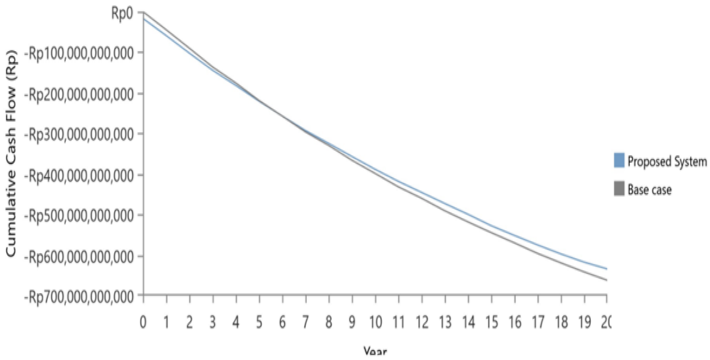

Figure 2. Cash Flow PLTS Banda Neira
Source: HOMER Pro Simulation Results, 2026.

Technical Analysis

The following is an overview or layout of PV systems that optimize the area of available solar PV land in Banda Neira. This system consists of 872 PV modules with a capacity of 550 Wp that are efficiently arranged according to land conditions so that it produces a total installed capacity of around 480 kWp. Module arrangement. This reference layout is designed with ease of access to installation, operation and maintenance in mind.

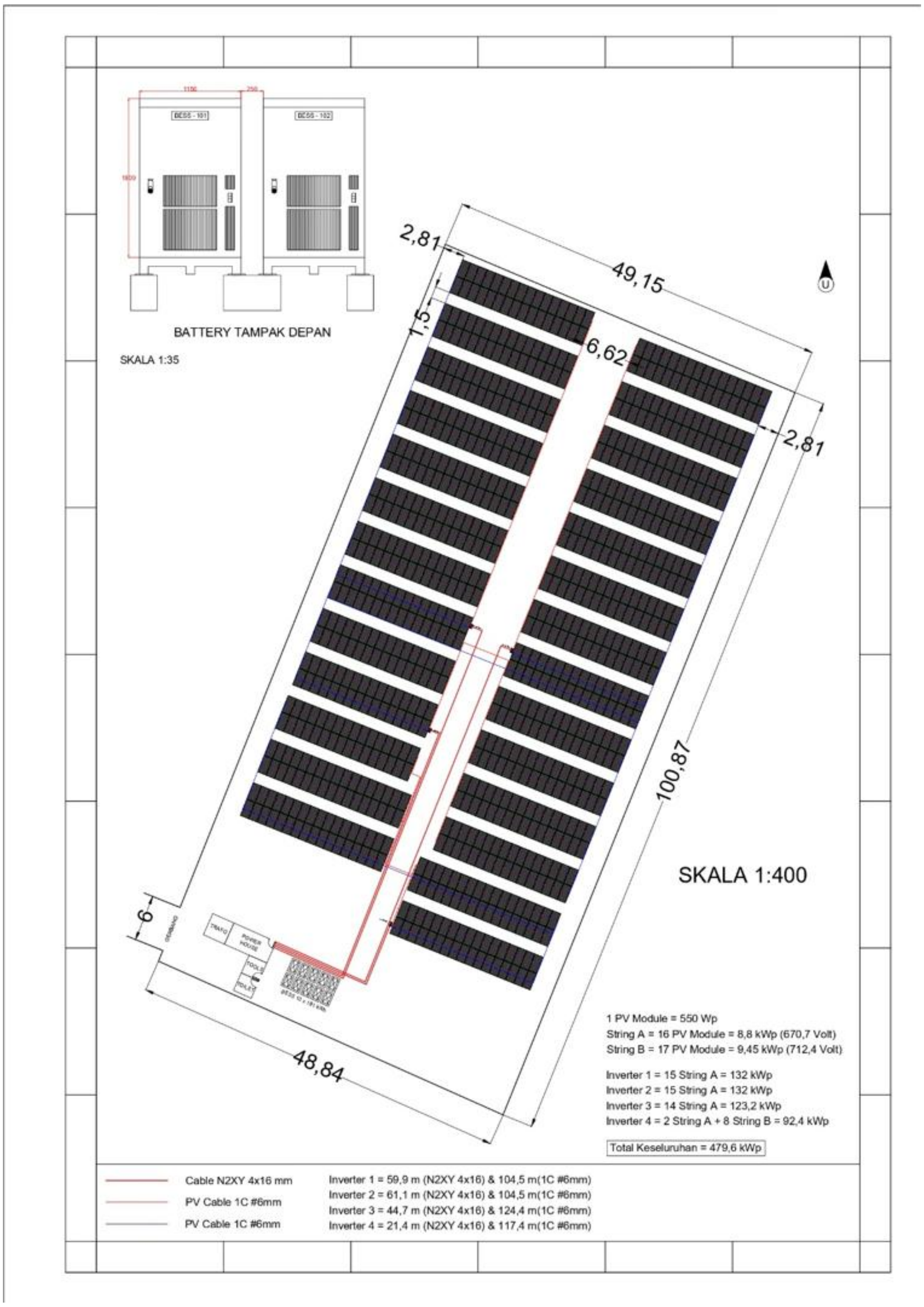

Figure 3. PV PLTS Banda Neira System Layout
Source: Author's Design, 2026.

Based on the results of the simulation using PVsyst, the solar PV system in Scenario 2 produces a Performance Ratio (PR) of 80.43%. This value shows that the designed solar system has good performance, where most of the solar energy received can be converted into electrical energy after taking into account various losses. In addition, the results of the HOMER Pro simulation show that the hybrid system configuration consisting of 480 kWp solar power plants and 1,610 kWh BESS is able to achieve a Renewable Fraction of 7%, which means that around 7% of the system's annual energy needs can be met from renewable energy sources. Although this value is relatively low, this condition is influenced by the high demand for electrical energy in the Banda system which reaches more than 8.4 GWh per year so that the contribution of solar energy to the total energy needs of the system is limited. However, this hybrid integration is still able to provide a reduction in fuel consumption, a reduction in operating costs, and a significant reduction in carbon emissions compared to existing conditions.

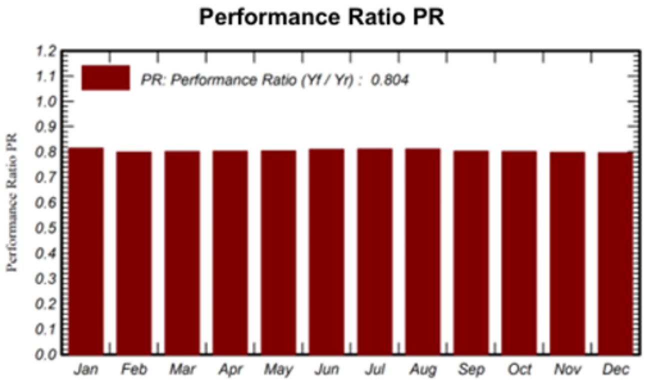

Figure 4. Performance Ratio PVSyst PLTS Banda Neira
Source: PVsyst Simulation Results, 2026.

Then, based on the modeling results on the HOMER Pro software, it can be seen in figures 4-5 below, which shows the daily operation profile of the Banda Neira Hybrid PV system with the Cycle Charging dispatch strategy taken from the January data sample. From the graph, it can be seen the contribution of each component to load fulfillment during the 24-hour period, including solar power plant production, diesel generator operation and battery charging and discharge processes.

In general, it can be seen that the system load is in the range of 900-1,100 kW throughout the day. PV production starts to increase in the morning and peaks around noon. However, the capacity of 480 kWp of solar power plants is still relatively small compared to the load requirements, so diesel generators remain the main source in this system.

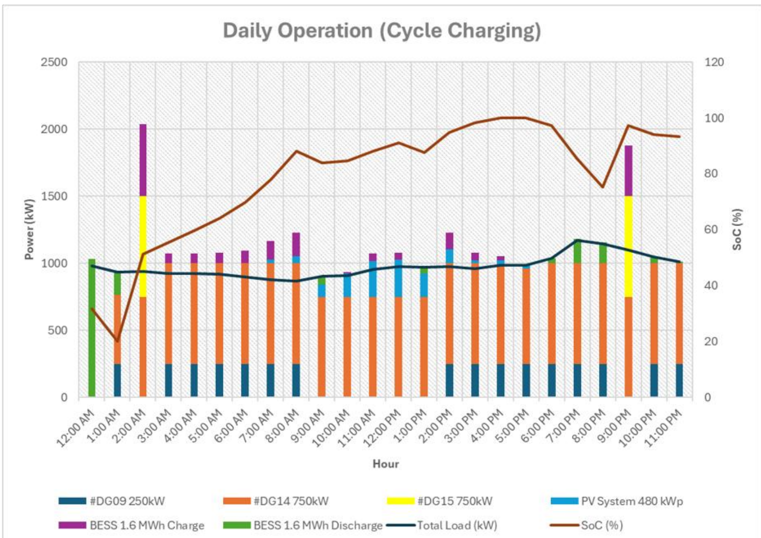

Figure 4. Operation Profile of Neira Island Hybrid Solar Power System
Source: HOMER Pro Simulation Results, 2026.

From the results of this simulation it can be seen that the battery does not operate continuously between full and minimum conditions, but rather undergoes several charge-discharge cycles of varying depths. The state of charge (SoC) value fluctuates between 20% to close to 100%. Then, in some periods, the battery only discharges a small amount before returning to the charging process. For example, in the morning to noon period the battery SoC decreases from around 88% to 84%, then increases again without first reaching the minimum SoC limit of 20%.

This condition shows the results of the Cycle Charging dispatch strategy applied in the HOMER Pro simulation. In this strategy, the goal of the system is not to discharge the battery to reach the minimum limit of the SoC, but to minimize the overall operating cost of the system. HOMER continuously evaluates the most economical combination of operations between the generator and the battery. Therefore, under some conditions, HOMER considers that maintaining the battery SoC at a relatively high level is more advantageous than draining the battery. A relatively high SOC value at some operating time does not indicate any system inefficiency. Rather, it indicates that the system maintains sufficient energy reserves to cope with load fluctuations and changes in generator operation or in the event of an emergency.

Thus, the resulting operating pattern for Scenario 2 reflects the results of optimization that minimizes the energy cost of the system by taking into account the load characteristics, solar power plant capacity, battery capacity, and performance of the diesel generator engine. With this scenario, load needs can still be met, system reliability is maintained, and the resulting LCOE value is lower than the system condition with only a generator engine, therefore the system configuration from Scenario 2 can be declared technically and economically feasible.

Managerial Implications

In this discussion, there are managerial implications where PT PLN Persero UP3 Maluku evaluates from the selection of the scenario of repairing the Neira Island solar power plant, where in the preparation of this study must ensure the condition of the existing system is operationally safe. In this case, the researcher communicates with the operator and determines the criteria considered for building the Neira Island Solar Power Plant using the AHP method. The result is that the reliability of the system becomes a top priority in the development stage. On the other hand, the economic factors of Scenario 2 reflect the results of optimization that minimize the energy cost of the system by considering the characteristics of the load, solar power plant capacity, battery capacity, and performance of the diesel generator engine so that in its construction it is waiting for the RKAP to be issued by PT PLN Persero for the repair of the Neira Island solar power plant.

CONCLUSION

Based on the findings of the techno-economic study on solar power plant improvement planning using the Analytical Hierarchy Process (AHP) method on Neira Island, Central Maluku, it was concluded that Scenario 2 represented the most suitable alternative for solar power plant rehabilitation. This scenario consisted of a 480 kWp photovoltaic (PV) system, a 1,610 kWh Battery Energy Storage System (BESS), and a Diesel Power Plant (Pembangkit Listrik Tenaga Diesel [PLTD]) as a supporting system. It demonstrated strong technical performance with a performance ratio (PR) of 80.43% and maintained electricity supply reliability through the integration of PV, BESS, and PLTD using a cycle charging dispatch strategy. Furthermore, Scenario 2 achieved the highest ranking in the Analytical Hierarchy Process (AHP) evaluation, in which system reliability was identified as the most influential criterion in decision-making. From an economic perspective, this scenario required an initial investment of IDR 16.69 billion and showed favorable financial indicators (Verbaan, 2001), including an internal rate of return (IRR) of 19%, a return on investment (ROI) of 15.2%, and a payback period of less than five years. In addition, its implementation reduced fuel consumption, decreased carbon emissions by approximately 530,469 kg CO_2 annually (9% compared with the existing system), and utilized available land more efficiently. Therefore, Scenario 2 was considered the optimal alternative because it provided a balanced solution across technical, economic, operational, and environmental aspects while supporting renewable energy transition in archipelagic electricity systems.

Future research should incorporate sensitivity analyses considering variations in solar irradiation conditions and potential increases in electricity demand on Banda Neira Island. Further studies should also examine developments in energy storage technologies, such as higher-efficiency lithium-ion battery systems, and explore the integration of additional renewable energy sources, including wind and micro-hydropower, to increase the renewable energy contribution. Moreover, developing a more comprehensive financial model that incorporates potential carbon credit mechanisms is recommended to strengthen the economic feasibility assessment of renewable energy projects in remote island regions.

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