Techno-economic analysis of a 4 MW solar photovoltaic capacity expansion in a remote Indonesian village

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ABSTRACT

As of the end of 2022, Indonesia’s electrification ratio reached 99.63%, reflecting significant progress. However, the province of East Nusa Tenggara lags behind with an electrification ratio below 90%, indicating a considerable gap in energy access. This challenge is particularly evident in Oelpuah village, where frequent power outages occur due to the inadequacy of the existing 5 MW solar farm. This study proposes addressing this shortfall by expanding the solar farm capacity by an additional 4 MW. Comprehensive feasibility studies were conducted, evaluating solar radiation, natural disaster risks, and land use. The analysis, supported by PVSyst simulations, identified a suitable site with high radiation levels, though it is not entirely free from disaster risks. The design requires 13,500 solar panel modules, each with a capacity of 330 Wp, and seven 500 kW inverters. Optimal system performance is achieved with a 15-degree panel tilt and a 0-degree azimuth, aligning with the site's location south of the equator. This expansion could supply electricity to up to 4,014 households, each with a typical power usage of 0.825 kW. The study highlights the need for further research to enhance electricity coverage across Indonesia.

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1. INTRODUCTION

The electrification ratio (RE) is a way of quantifying the percentage of an area that has electricity. In general, villages in Indonesia already have achieved almost 100% in 2020 (MEMR 2021) [1], [2]. The latest data shows that Indonesia already has a high RE value, at 99.63% by the end of 2022 [3]. In order to achieve a high electrification ratio target, especially in remote areas and islands, the utilization of renewable energy become very relevant [4], [5]. Renewable energy such as solar power plants, with their ability to provide electricity independently without relying on the main grid, provide a good solution to increase the electrification ratio and also minimalizing carbon dioxide (CO_2) emission [6]–[8]. By integrating solar power plants, especially in areas that are difficult to reach by conventional power grids, the government can accelerate the improvement of electricity access while supporting the energy transition agenda towards cleaner and more sustainable energy sources [9], [10].

Several large solar power plants have been built in Indonesia, such as Cirata floating photovoltaic 145 MWp [11], [12] and power solar plant in Oelpuah. Oelpuah solar power plant, located in Oelpuah Village, Kupang Tengah District, Kupang Regency, East Nusa Tenggara, is the largest solar power plant in

Indonesia with a capacity of 5 MWp [13]. However, this is considered insufficient to meet the demand. Therefore, a simulation will be conducted to assess the impact of adding an additional 4 MWp in solar power plant system.

However, this value when compared to East Nusa Tenggara Province is quite far [14], which is 92,20%. Specifically, in Oelpuah village, this electricity distribution is still not fully achieved [15]. Existing efforts to build a solar farm with a capacity of 5 MW are still not enough to meet the needs of residents. From this 5 MW, an additional 4 MW of power is still needed to avoid a deficit. The need for 4 MW is the objective of this research. This research will determine the most appropriate location by conducting feasibility studies related to the potential of solar radiation, natural disasters, existing land use, and the distance to on-grid electricity. The following is information about the position of Oelpuah Village which will be the place to fulfill the objectives of this research as shown in Figure 1.

Figure 1. Kupang Regency in Nusa Tenggara Timur Province

Oelpuah Village is located in East Nusa Tenggara Province and is in the Kupang Regency [16], [17]. The area is divided into 3 parts with the main part being in the easternmost part. Based on data from Dukcapil, the village has 1,628 residents with 369 families. Data from the Ministry of Education and Culture shows that the area of Olpuah Village reaches 360,000 m^2.

In addition to meeting electricity needs, Oelpuah village itself has excellent potential [13] to be placed in a solar farm because based on data from the Global Solar Atlas, Oelpuah village and East Nusa Tenggara Province as a whole do have high solar radiation potential when compared to other provinces in Indonesia. Based on the Global Solar Atlas, the direct normal irradiation (DNI) values of Oelpuah village are 2,045 kWh/m^2 higher than Jakarta which has 917 kWh/m^2. Direct normal irradiance (DNI) refers to the solar energy received per unit area by a surface that is oriented perpendicular to the direction of the sunlight, covering the entire solar spectrum [18], [19]. In terms of air temperature, the temperature of Oelpuah Village is also still in the category suitable for a solar farm, which is 26.6 ^oC. This shows that solar energy is a suitable energy source to be utilized as a source of electricity in this village compared to other energy sources such as water and wind.

Several research was conducted by some researches in several locations. Ohanu *et al.* proposes a high-precision solar radiation estimation model in Nigeria. The model outperforms 8 conventional models and PVSyst, achieving an estimation precision of 94.70% to 97.19%, compared to 87.53% to 96.74% for conventional models and 90.38% to 95.96% for PVSyst [20]. Dellosa *et al.* examined the technical and economic feasibility of a 5 MWp solar photovoltaic (PV) farm in Butuan City, Philippines, using PVSyst software for simulations. This project, with an investment of approximately 300 million pesos (USD 6.25 million), shows a promising payback period of 4.23 years and an ROI of 506.2%. Additionally, the PV farm is expected to avoid 109,828.4 tons of CO_2 emissions over its operational lifetime, supporting the recommendation for the project's implementation [21]. For rooftop PV system, Nuri Caglayan's study evaluates a 216 kWp rooftop PV system that generates 326,819 kWh/year, with a performance ratio of 0.808, an NPV of $36,463.39, and an LCOE of $0.065/kWh. The system is projected to prevent 127.419 tons of CO_2 emissions annually, with an annual electricity generation of 315,152 kWh [22]. In floating PV case, Srinivasan *et al.* [23] and Miah *et al.* [24] analyzed the technical and economic feasibility of floating solar PV. That PV plants also have the potential to reduce CO_2 emissions. A study by Fahmy *et al.* finds that a rooftop photovoltaic system on Building C (New Media Tower) at Universitas Multimedia Nusantara is both technically and financially feasible, with an annual energy production of 202 MWh, a payback period of 8.2 years, and an ROI of 115.8%. This highlights the rooftop system's superiority over the parking area system and its potential to support sustainable energy initiatives in academic institutions [25].

The novelty of this research includes the prediction that Oelpuah village requires an additional 4 MW from a solar photovoltaic (PV) plant to improve the electrification ratio, as the existing 5 MW PV plant is insufficient. The study highlights the high solar energy potential in Oelpuah village, with a direct normal irradiance (DNI) of 1,128 kWh/m² and favorable air temperature, making it an ideal location for a PV plant. Additionally, the research includes a comprehensive technical and economic feasibility analysis, including the modeling of equipment such as the type and number of solar panels, inverters, as well as considerations for disaster risks and land use.

2. FEASIBILITY STUDIES DATA

The methodology includes several steps. The first step in determining the most potential site for the solar farm is to gather and analyze crucial data specific to Oelpuah village. This includes solar radiation data, forest fire risk data, flood risk data, landslide risk data, and earthquake risk data. Each of these aspects will be systematically explained to provide a clear understanding of the optimal site location. This analysis will help ensure that the chosen location not only has high solar radiation potential but also minimal natural disaster risks, thereby ensuring the efficiency and safety of the solar farm's future operations.

2.1. Solar radiation data

Data from the Global Solar Atlas shows variations in solar radiation throughout the year, which can help in analyzing the solar energy potential of Oelpuah village. Based on Figure 2, in June, the red-colored areas on the radiation map indicate the points with the highest radiation intensity. This makes it a very potential month for solar energy production.

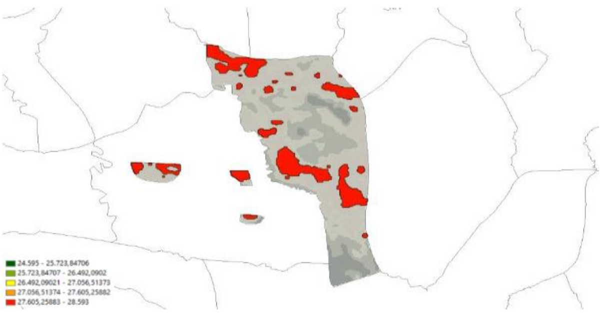


Figure 2. High solar radiation Map in Oelpuah village in June

2.2. Forest fire risk data

The second most necessary aspect in determining the ideal site for a solar farm is the potential for forest fires. This is because forest fires can affect the ambient temperature of the burned area and can produce dust from burning leaves and, twigs, and wood from trees. Both of these affect the effectiveness of the solar panels as dust covering the solar panels can reduce the effectiveness of the solar panels as solar radiation cannot be fully received. On the other hand, the rising temperatures from forest fires are also very influential because solar panels can only work effectively at temperatures that have been determined by the solar panel product chosen. And of course, if the forest fire spreads to the solar farm site, it will damage the solar panel components themselves.

Figure 3 is the resulted figure with ArcGIS software. The figure data shows that Oelpuah village does have a high potential (red) for forest fires. However, based on this data from the BPBD of East Nusa Tenggara Province, there are still areas that are still in the medium category (yellow). Efforts such as having land that does not have so much vegetation are also a consideration to minimize solar farm fires.

2.3. Flood risk data

Flooding is the second aspect to be considered because based on the study conducted by the author, no news was found discussing landslides and earthquakes in this village. Figure 4 is a map of flood disaster risk in Oelpuah village according to the BPBD of East Nusa Tenggara Province. This figure is processed with ArcGIS software. The data shows that, on the whole, Oelpuah village has minimal potential for flooding. However, there is a small part of the village, namely the eastern part (red) that has a high potential for flooding. Nevertheless, the areas of the village that are not at risk of flooding are still very large and not a major problem.

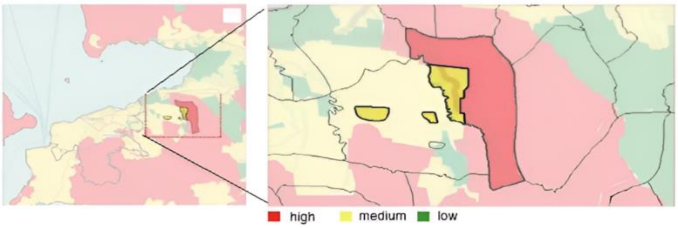


Figure 3. Forest fire risk Map of Oelpuah village
(source: East Nusa Tenggara Province Disaster Mitigation Agency)

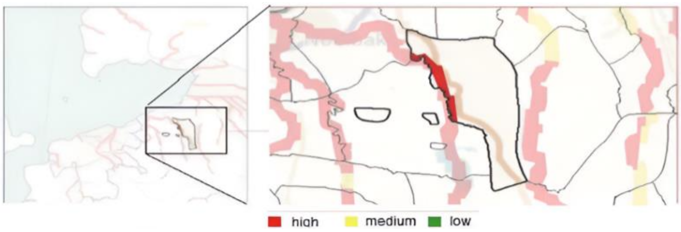


Figure 4. Flood risk Map of Oelpuah village
(source: East Nusa Tenggara Province Disaster Mitigation Agency)

2.4. Data collecting

The next disaster of concern is landslides. Landslides are positioned in the 3rd most important aspect because Oelpuah village does not often experience landslides, and there is no news related to landslides in this village. Thus, landslides are not a top priority for the author in determining the ideal site position. Figure 5 is a map of the risk of landslides in Oelpuah village according to the BPBD of East Nusa Tenggara Province. This landslide risk map in Figure 5 is processed by using ArcGIS software.

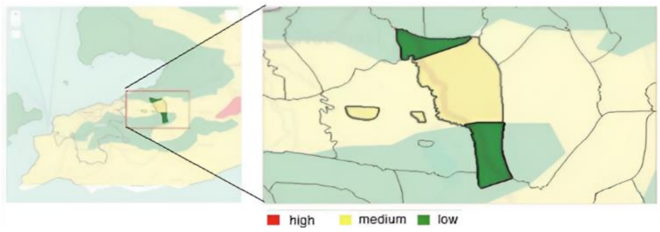


Figure 5. Landslide risk Map of Oelpuah village
(source: East Nusa Tenggara Province Disaster Mitigation Agency)

The data supports the previous statement that Oelpuah village is not at risk of landslides. It can be said that half of Oelpuah village is not at risk of landslides and the other half is at moderate risk of landslides. There are no areas in the village that are at high risk. Thus, the village can be said to be still safe from the threat of landslides.

2.5. Earthquake risk data

The last disaster aspect that needs to be considered in determining the position of the solar farm is earthquake disaster. This aspect is positioned in the last aspect because earthquakes tend to have an impact on a large area. Thus, it can be said that all areas in Oelpuah village will receive an equally large impact in the event of an earthquake. Figure 6 is an earthquake disaster risk map in Oelpuah village according to the BPBD of East Nusa Tenggara Province that processed by ArcGIS software.

The data shows that Oelpuah village does have a medium-high potential to be affected by earthquakes, but this problem can be justified by the low potential for damage from the solar farm as the structures used are low-grade and the likelihood of damage is low. The buildings in the village also tend to be low-rise, so the potential for collapsing buildings is low. Thus, the risk of earthquakes can be excluded from the feasibility studies, but can be responded to by selecting a site away from buildings and high vegetation because most of the village is potentially affected by earthquakes.

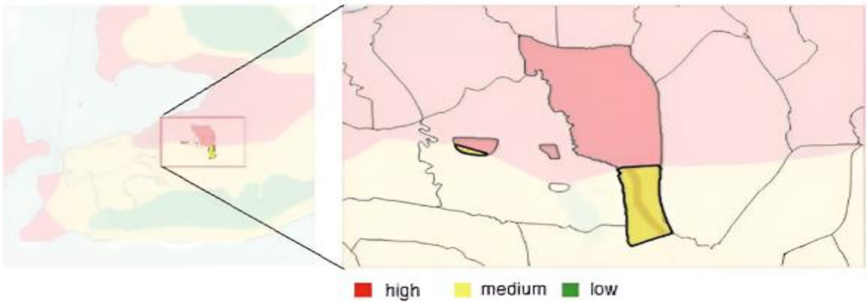


Figure 6. Earthquake risk Map in Oelpuah village
(source: East Nusa Tenggara Province Disaster Mitigation Agency)

3. AREA ELIMINATION AND SITE SELECTION

After obtaining specific information on solar radiation and potential disaster risks in Oelpuah village, will be decide the site area elimination and selection. This section will discuss how the authors determined the optimal site by layering the aforementioned data. This section will explain the processes of area elimination and site selection.

3.1. Area elimination

The final site selection for the solar power plant construction was based on the integration of several data, namely areas with high solar radiation, low risk of forest fires, and no risk of flooding. Oelpuah village did not consider landslide risk as it is classified as very low, while earthquake risk was also ignored as the impact is evenly distributed across the area and the low structure of the solar power plant reduces the potential damage. The final results of the site selection are shown in Figure 7, with potential areas marked with numbers 1, 2 and 3 as the most suitable locations for solar power plant construction.

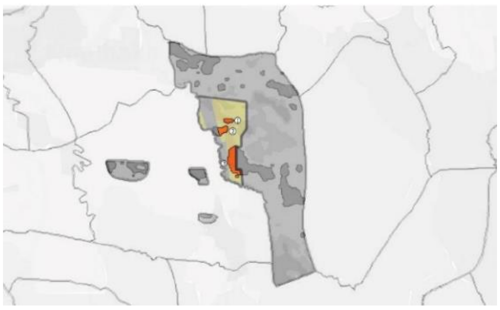


Figure 7. Final potential areas for solar farm with numbers

3.2. Site selection

There are three potential site areas. However, the one of the sites (sites number 1) is eliminated because it is the location coincide with existing 5 MW solar farm owned by Oelpuah village. Therefore, the remaining sites are only two, which is site 2 and 3 as shown in Figures 8 and 9.

The first potential area for the additional solar farm is shown on Figure 8. The red-marked areas are those eliminated because the areas not outlined in red are still used as residential land (indicated by red dots). The area outlined in red is the final usable area since it is not used for housing and is adjacent to a road, which is necessary for electricity distribution as the solar farm is on-grid. This site is also quite large, with an area of 34,279 m². The selected area consists of sparse vegetation and is currently unused, making it suitable for a solar farm as it does not interfere with existing land use, requires minimal tree cutting, and has a low risk of forest fires due to the lack of dense surrounding vegetation.

Figure 8. Potential zone 1 for additional solar farm

In Figure 9, the red-marked area is without additional eliminations as there are no residences or buildings within it. This area is also not far from the existing 5 MW Oelpuah solar farm and is relatively close to the road. Although there may be additional cable loss, it is not significant. Compared to site number 2, this area is slightly larger, with an area of 37,681 m². However, this site is less suitable for a solar farm as it is agricultural land with dense surrounding vegetation. This site would require repurposing existing land use and has a higher potential for forest fires due to the dense trees nearby. A summary of the criteria and selection of potential zones is shown in the table below. Then, Table 1 indicates that the most ideal site for the solar farm is site number 2.

Figure 9. Potential zone 2 for additional solar farm

Table 1. Summarizes the site selection for the solar farm

Site Num.	Aspects of consideration		
	Risk of forest fire	Existing function	Area distance to road
1	Eliminated	Eliminated	Eliminated
2	Low (minimum vegetation around site area)	Not used	Next to the road
3	High (dense vegetation around site area)	Agriculture	Close to the road

4. SOLAR FARM SYSTEM ANALYSIS

4.1. Finding the ideal Tilt and Azimuth

Based on data from the Global Solar Atlas, the optimal tilt and azimuth that receive the highest solar radiation are a 15-degree tilt with a 0-degree azimuth. The 0-degree azimuth, meaning the solar panels face north, is due to Oelpuah village's location south of the equator, where the sun predominantly shines from the north. In addition to the Global Solar Atlas, the ideal tilt was also checked using PVSyst. Table 2 shows the results, which confirm that the most ideal tilt and azimuth for the solar panels are 15/16 degrees with a 0-degree azimuth.

4.2. System analysis and summary

As shown in Figure 10, to achieve 4 MW (specifically 4.024 MW), the solar farm requires 13,500 units of Seraphim 330 Wp solar panels (SRP-330-E01B). In comparison, the existing Oelpuah solar power plant uses 22,008 solar panels with 230 Wp to generate 5 MW. The system utilizes 7 inverters with a capacity of 500 kWac each, totaling 3,500 kWac. The tilt used is 15 degrees with a 0-degree azimuth (facing north). The solar farm system is on-grid to minimize costs by avoiding the need for batteries. This allows for a faster payback period, enabling the funds to be used for developing other solar farms.

Table 2. Finding the ideal Tilt for solar panel

Tilt	0 Degree Azimuth Energy production (kWh/m^2/yr)
30	2271
25	2307
20	2328
18	2332
16	2334
15	2334
13	2333
11	2329
10	2326
5	2302
0	**2265**

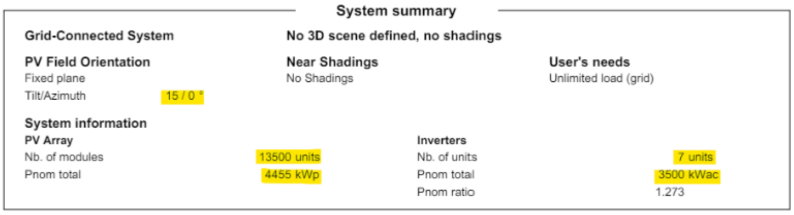


Figure 10. PVSyst simulation system summary

According to the system information in Figure 11, the total module area will cover 22,962 m². This is sufficient for the site, which spans 34,279 m², leaving 11,317 m² available for inverter rooms, other equipment, circulation areas, and potential future expansion of the solar farm. This system can produce 7,855,688 kWh/year or 1,763 kWh/kWp/year, as estimated in Figure 12.

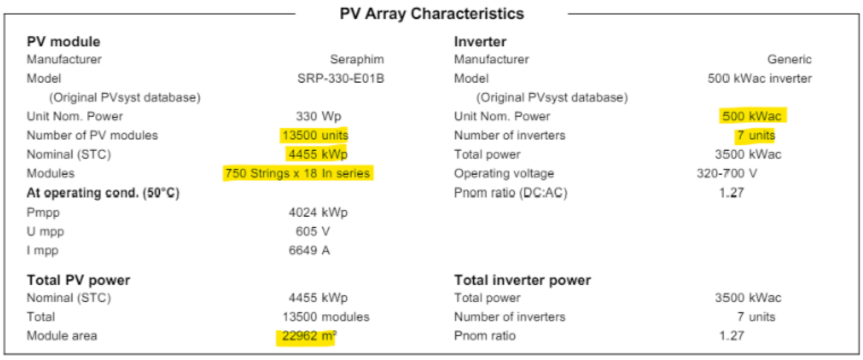


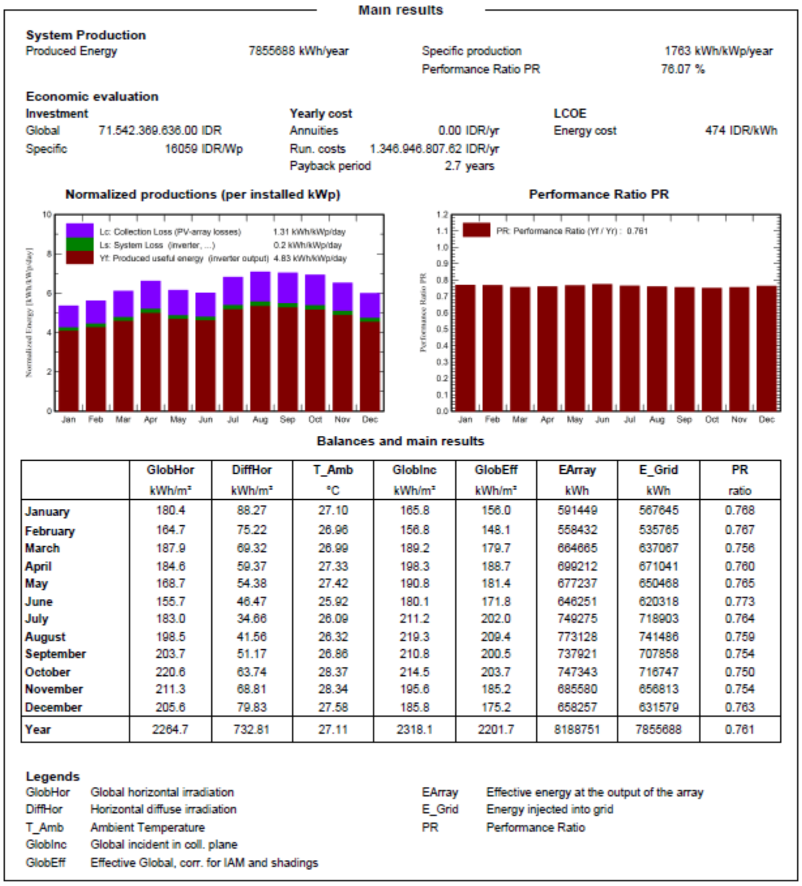
Figure 11. PVSyst simulation PV array characteristics

Figure 12. PVSyst simulation system production summary

4.3. Energy production detail

Simulation results in Figure 13 show monthly energy production per kWp. The table indicates that the highest production occurs in October, with energy per square meter reaching 220.6 kWh/m². The result presents the performance analysis of a photovoltaic system, showing an annual energy production of

7,856,688 kWh, with a specific production of 1,763 kWh/kWp/year and a performance ratio of 76.07%. The economic evaluation includes an investment of 71.5 billion IDR, resulting in an energy cost (LCOE) of 474 IDR/kWh and a payback period of 2.7 years. The graphs illustrate monthly energy production per installed kWp and a stable performance ratio throughout the year, supported by monthly data on global irradiation, ambient temperature, and energy output.



Main results

System Production
Produced Energy 7855688 kWh/year
Specific production 1763 kWh/kWp/year
Performance Ratio PR 76.07 %

Economic evaluation
Investment
Global 71.542.369.636.00 IDR
Specific 16059 IDR/Wp
Yearly cost
Annuities 0.00 IDR/yr
Run. costs 1.346.946.807.62 IDR/yr
Payback period 2.7 years
LCOE
Energy cost 474 IDR/kWh

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	180.4	88.27	27.10	165.8	156.0	591449	567645	0.768
February	164.7	75.22	26.96	156.8	148.1	558432	535765	0.767
March	187.9	69.32	26.99	189.2	179.7	664665	637067	0.756
April	184.6	59.37	27.33	198.3	188.7	699212	671041	0.760
May	168.7	54.38	27.42	190.8	181.4	677237	650468	0.765
June	155.7	46.47	25.92	180.1	171.8	646251	620318	0.773
July	183.0	34.66	26.09	211.2	202.0	749275	718903	0.764
August	198.5	41.56	26.32	219.3	209.4	773128	741486	0.759
September	203.7	51.17	26.86	210.8	200.5	737921	707858	0.754
October	220.6	63.74	28.37	214.5	203.7	747343	716747	0.750
November	211.3	68.81	28.34	195.6	185.2	685580	656813	0.754
December	205.6	79.83	27.58	185.8	175.2	658257	631579	0.763
Year	2264.7	732.81	27.11	2318.1	2201.7	8188751	7855688	0.761

Legends
GlobHor Global horizontal irradiation
DiffHor Horizontal diffuse irradiation
T_Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Figure 13. System energy production detail

4.4. Single line diagram

The single-line diagram in Figure 14 illustrates the electrical configuration of a PV system, highlighting the connection from the solar panel arrays to the grid injection point. Each string consists of 18 solar panel modules, and the system comprises a total of 750 strings distributed across multiple inverters. Six inverters, each with a capacity of 3,000 kVA, handle the majority of the energy conversion, while an additional inverter with a capacity of 500 kVA supports the system. The short cable distance of 96.0 meters between the inverters and the medium-voltage transformer minimizes energy losses, facilitated by the site's close proximity to the road. The medium-voltage transformer, rated at 20 kV, connects the system to the grid at the injection point, ensuring efficient energy transfer. This setup is optimized for large-scale energy production while maintaining technical efficiency and reliability.

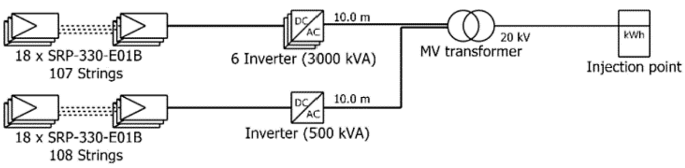


Figure 14. System single line diagram

4.5. Energy losses

Figure 15 outlines the energy losses in a photovoltaic system, starting from an initial global horizontal irradiation of 2,265 kWh/m², which reduces to 2,202 kWh/m² on the collector plane after accounting for a 3% soiling loss and IAM factors. The most significant loss, 12.61%, is caused by temperature effects on the PV modules, while smaller losses include module quality (-0.75%), light-induced degradation (-0.20%), and mismatches (-0.34%). Wiring losses of 1.21% arise from the 10-meter distance between the inverter and transformer, along with inverter losses like operational inefficiencies (-2.90%). After all adjustments, the system injects 7,856,688 kWh into the grid, emphasizing temperature as the primary factor affecting energy efficiency.

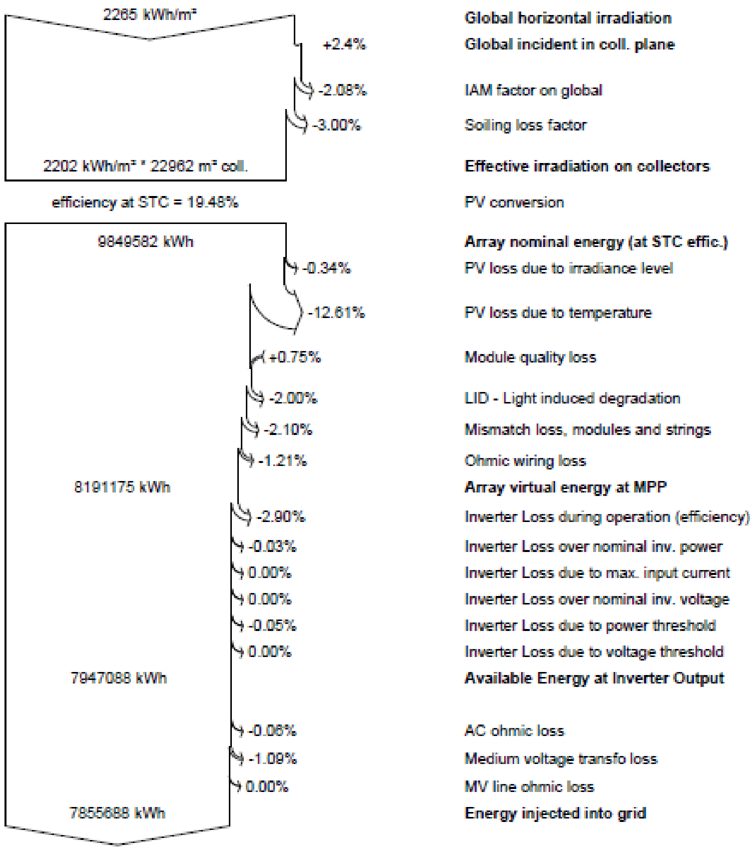


Figure 15. Energy losses diagram

4.6. Economic evaluation

Figure 16 explain that in terms of production costs, it takes IDR 5,059 to generate 1 Wp, and IDR 474 to produce 1 kWh. These production costs are considerably lower than the selling price of IDR 3,450. Therefore, it can be concluded that the energy sold yields a profit margin of 627.85% over its production cost. On the other hand, the investment cost is quite high, at IDR 71,542,369,636, or approximately IDR 71 billion.

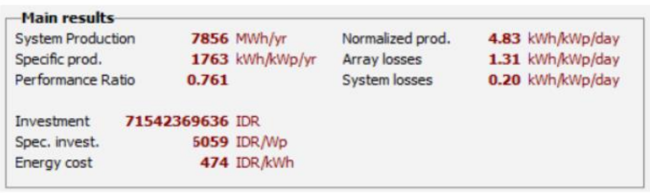


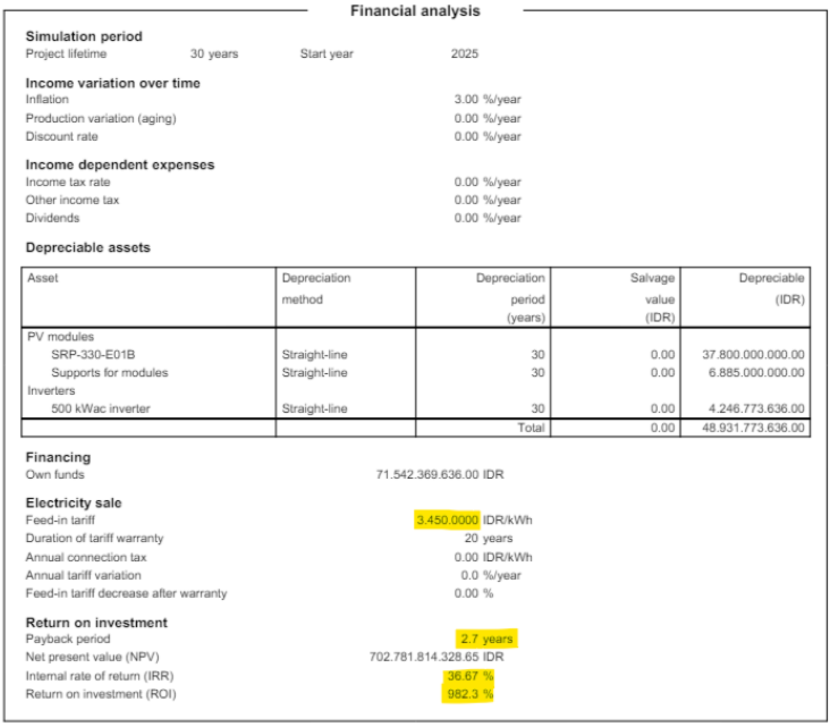
Figure 16. Main results for economic evaluation

The 71-billion-rupiah investment is calculated based on the unit costs in Table 3, multiplied by the number of units used. Out of this IDR 71 billion, assets like solar panels, support structures, and inverters will gradually deteriorate and need replacement/repair, with a depreciable asset value of IDR 48,931,773,636, or 48 billion, accounting for approximately 68.4% of the assets. Additional maintenance costs are also considered, amounting to IDR 1,346,946,807, or 1.3 billion annually, which will be deducted from the revenue to calculate the payback period.

According to the PVSyst calculations in Figure 17, the investment payback period is 2.7 years. This rapid payback is due to the low energy production cost per kWh (474) being sold at a relatively high price of 3,450. The Internal Rate of Return (IRR) is 36.67%, and the Return on Investment (ROI) is 982.3% over 30 years. Figure 18 illustrates the overall income and expenses. The initial IDR 71 billion investment is shown as an outlay in the first year. On the right side is the annual income of IDR 27 billion from energy sales. The investment is recouped in year 2.7 when the cumulative profit changes from orange to green. This profit is after accounting for depreciation costs or asset replacement due to wear and tear, amounting to IDR 1.6 billion per year, as well as increasing maintenance costs each year due to 3% inflation. The net profit is shown as after-tax profit.

Table 3. System product pricing

Num.	Product	Pricing (IDR/unit)	Source
1	SRP-330-E01B	2,800,000	Tokopedia
2	500kW ABB inverter ACS580-04-880A-4	607,141,776	shiny-control.en.made-in-china.com
3	Solar panel support structure	510,000	kompas.com
4	Wiring	680,000	atonergi.com


Financial analysis

Simulation period
Project lifetime 30 years Start year 2025

Income variation over time
Inflation 3.00 %/year
Production variation (aging) 0.00 %/year
Discount rate 0.00 %/year

Income dependent expenses
Income tax rate 0.00 %/year
Other income tax 0.00 %/year
Dividends 0.00 %/year

Depreciable assets

Asset	Depreciation method	Depreciation period (years)	Salvage value (IDR)	Depreciable (IDR)
PV modules				
SRP-330-E01B	Straight-line	30	0.00	37.800.000.000.00
Supports for modules	Straight-line	30	0.00	6.885.000.000.00
Inverters				
500 kWac inverter	Straight-line	30	0.00	4.246.773.636.00
		Total	0.00	48.931.773.636.00

Financing
Own funds 71.542.369.636.00 IDR

Electricity sale
Feed-in tariff 3.450.0000 IDR/kWh
Duration of tariff warranty 20 years
Annual connection tax 0.00 IDR/kWh
Annual tariff variation 0.0 %/year
Feed-in tariff decrease after warranty 0.00 %

Return on investment
Payback period 2.7 years
Net present value (NPV) 702.781.814.328.65 IDR
Internal rate of return (IRR) 36.67 %
Return on investment (ROI) 982.3 %

Figure 17. Financial analysis

Then, Figure 19 further clarifies the cash flow over the years. It shows that by year 2.7, a profit has already been generated, which would be in 2027. The economic analysis above demonstrates that this solar farm can generate substantial profits with a payback period of just 2.7 years. This is due to efforts to minimize energy production costs per kWh and reduce investment costs by selecting relatively cheaper products with good performance. Additionally, the low land costs in the village also help to reduce overall expenses. However, it cannot be denied that the selling price of energy per kWh at IDR 3,450 is very high, likely due to government subsidies aimed at encouraging the public to use electricity from renewable energy sources.

Detailed economic results (kIDR)

Year	Electricity sale	Own funds	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
0	0	71.542.369.636	0	0	0	0	0	-71.542.369.636	0.0%
1	27.157.752.940	0	849.354.727	1.631.059.121	24.677.339.091	0	26.308.398.213	-45.233.971.423	36.8%
2	27.157.752.940	0	874.835.369	1.631.059.121	24.651.858.450	0	26.282.917.571	-18.951.053.853	73.5%
3	27.157.752.940	0	901.080.430	1.631.059.121	24.625.613.388	0	26.256.672.510	7.305.618.657	110.2%
4	27.157.752.940	0	928.112.843	1.631.059.121	24.598.580.976	0	26.229.640.097	33.535.258.754	146.9%
5	27.157.752.940	0	955.956.228	1.631.059.121	24.570.737.590	0	26.201.796.711	59.737.055.465	183.5%
6	27.157.752.940	0	984.634.915	1.631.059.121	24.542.058.903	0	26.173.118.025	85.910.173.490	220.1%
7	27.157.752.940	0	1.014.173.963	1.631.059.121	24.512.519.856	0	26.143.578.977	112.053.752.467	256.6%
8	27.157.752.940	0	1.044.599.181	1.631.059.121	24.482.094.637	0	26.113.153.758	138.166.906.225	293.1%
9	27.157.752.940	0	1.075.937.157	1.631.059.121	24.450.756.662	0	26.081.815.783	164.248.722.008	329.6%
10	27.157.752.940	0	1.108.215.272	1.631.059.121	24.418.478.547	0	26.049.537.668	190.298.259.677	366.0%
11	27.157.752.940	0	1.141.461.730	1.631.059.121	24.385.232.089	0	26.016.291.210	216.314.550.887	402.4%
12	27.157.752.940	0	1.175.705.582	1.631.059.121	24.350.988.237	0	25.982.047.358	242.296.598.245	438.7%
13	27.157.752.940	0	1.210.976.749	1.631.059.121	24.315.717.069	0	25.946.776.191	268.243.374.435	474.9%
14	27.157.752.940	0	1.247.306.052	1.631.059.121	24.279.387.767	0	25.910.446.888	294.153.821.324	511.2%
15	27.157.752.940	0	1.284.725.233	1.631.059.121	24.241.968.585	0	25.873.027.707	320.026.849.030	547.3%
16	27.157.752.940	0	1.323.266.990	1.631.059.121	24.203.426.828	0	25.834.485.950	345.861.334.980	583.4%
17	27.157.752.940	0	1.362.965.000	1.631.059.121	24.163.728.819	0	25.794.787.940	371.656.122.920	619.5%
18	27.157.752.940	0	1.403.853.950	1.631.059.121	24.122.839.869	0	25.753.898.990	397.410.021.910	655.5%
19	27.157.752.940	0	1.445.969.568	1.631.059.121	24.080.724.250	0	25.711.783.371	423.121.805.281	691.4%
20	27.157.752.940	0	1.489.348.655	1.631.059.121	24.037.345.163	0	25.668.404.284	448.790.209.566	727.3%
21	27.157.752.940	0	1.534.029.115	1.631.059.121	23.992.664.704	0	25.623.723.825	474.413.933.390	763.1%
22	27.157.752.940	0	1.580.049.988	1.631.059.121	23.946.643.830	0	25.577.702.951	499.991.636.342	798.9%
23	27.157.752.940	0	1.627.451.488	1.631.059.121	23.899.242.330	0	25.530.301.452	525.521.937.793	834.6%
24	27.157.752.940	0	1.676.275.033	1.631.059.121	23.850.418.786	0	25.481.477.907	551.003.415.700	870.2%
25	27.157.752.940	0	1.726.563.284	1.631.059.121	23.800.130.535	0	25.431.189.656	576.434.605.356	905.7%
26	27.157.752.940	0	1.778.360.182	1.631.059.121	23.748.333.636	0	25.379.392.758	601.813.998.114	941.2%
27	27.157.752.940	0	1.831.710.988	1.631.059.121	23.694.982.831	0	25.326.041.952	627.140.040.066	976.6%
28	27.157.752.940	0	1.886.662.317	1.631.059.121	23.640.031.501	0	25.271.090.622	652.411.130.688	1011.9%
29	27.157.752.940	0	1.943.262.187	1.631.059.121	23.583.431.632	0	25.214.490.753	677.625.621.441	1047.2%
30	27.157.752.940	0	2.001.560.052	1.631.059.121	23.525.133.766	0	25.156.192.887	702.781.814.329	1082.3%
Total	**814.732.588.193**	**71.542.369.636**	**40.408.404.229**	**48.931.773.636**	**725.392.410.329**	**0**	**774.324.183.965**	**702.781.814.329**	**1082.3%**

Figure 18. Detailed economic results

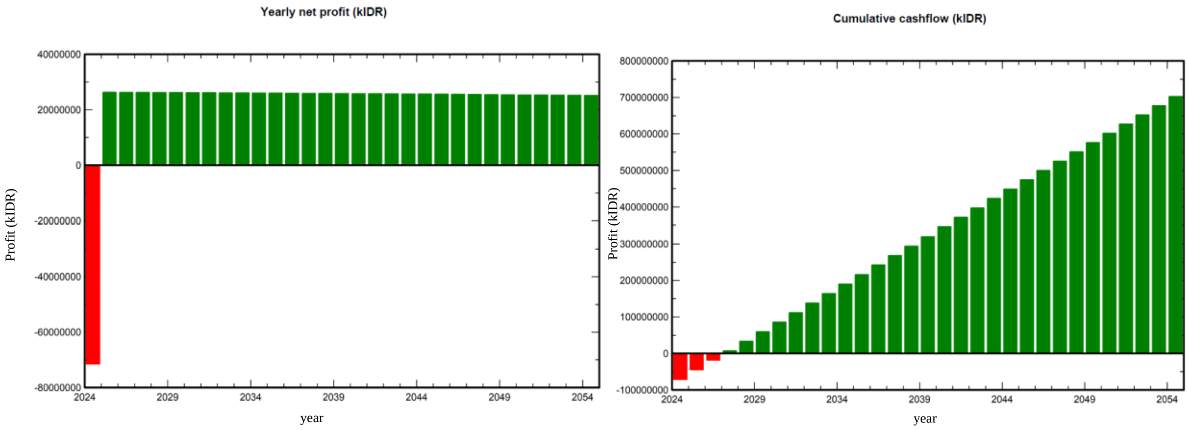


Figure 19. Financial analysis yearly net profit

4.7. Solar farm capacity

The residents of Oelpuah village still suffer from electricity shortages due to a 4 MW deficit in power production in the area. As a result, power outages are still common because the existing solar farm is unable to meet the electricity needs of Oelpuah village and the surrounding areas. Table 4 is an assessment of the impact of adding this additional 4 MW solar farm to the existing one.

If the solar farm system's calculations indicate that it has a maximum operating power of 4,024 kW or 4.024 MW, the number of households it can cover is 4,877 (4,024 kW divided by 0.825 kW) households or families. Therefore, Figure 20 is the map shows the households that can be covered by this additional solar farm and Table 5 is detailed village list.

Table 4. Power usage for typical household

Num.	Appliance	Power (W)	Unit	Total power (W)
	Typical power usage for a household			
1	LED Lamp	5	5	25
2	TV	50	1	50
3	Fan	50	1	50
4	Rice Cooker	300	1	300
5	Iron	300	1	300
6	Refrigerator	100	1	100
		Total		825

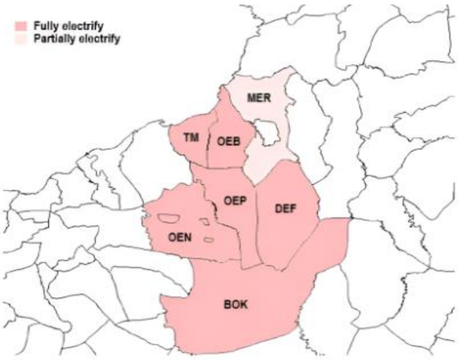


Figure 20. Number of households covered by additional 4 MW solar farm

Table 5. Coverage from additional solar farm

Num.	Village	Household coverage Num. of household	Household coverage left
1	Oelpuah (OEP)	369	4508
2	Oelnasi (OEN)	557	3951
3	Oefafi (DEF)	578	3373
4	Bokong (BOK)	655	2718
5	Tanah Merah (TM)	923	1795
6	Oebelo (OEB)	1299	496
7	Merdeka (MER)	755	-259

These results indicate that the addition of this 4 MW solar farm can fully meet the electricity needs of six villages and partially meet the needs of one village. The map above shows which villages are prioritized for electricity supply from this additional solar farm, focusing on those adjacent to Oelpuah village to minimize cable losses. Regarding the potential issues in distributing electricity from the solar farm to the surrounding community, the following potential issues are addressed:

a. Social: Based on the construction of the existing Oelpuah solar farm, the author did not find any reports of opposition to the development of the solar farm. However, the author has also considered the site location, where the land used is not currently utilized for any purpose, minimizing the likelihood of land acquisition issues from residents. This is also supported by reports that Oelpuah residents are grateful for the construction of the existing solar farm as it has helped reduce rotating blackouts.
b. Technical: Energy production fluctuations are one of the most significant concerns in solar farm installations. The on-grid solar farm type cannot store backup electricity if bad weather persists for an extended period. However, on-grid solar farms are a much more economical investment compared to off-grid solar farms. The author suggests installing the on-grid solar farm first. In a few years, once the solar farm has recouped its investment, additional solar farms can be added elsewhere, minimizing the risk of insufficient electricity due to prolonged bad weather.

4.8. Carbon dioxide reduction

Using solar panels can prevent the release of CO_2 into the atmosphere, as the electricity we currently use is still generated from coal, which produces CO_2. Before discussing the CO_2 emissions avoided, the grid LCE was manually entered based on data from the 2019-2028 RUPTL, which states that carbon emissions from power plants in the Java, Bali, and Nusa Tenggara areas are 0.817 tons of CO_2/MWh. Converted to

gCO_2/kWh, this value is 741 gCO_2/kWh. The results of PVSyst calculation, over 30 years, this solar farm can prevent the release of 142,964.344 tons of CO_2 from power plants. If we look at the significance of current PV technology developments in reducing the carbon footprint, several aspects contribute to this reduction such as solar panel efficiency. The higher the efficiency of the solar panels, the greater the potential for electricity production. The more electricity generated from renewable sources, the less electricity is required from non-renewable sources. In this additional solar farm project, Seraphim 330 Wp (SRP-330-BMB-HV) solar panels with an efficiency of 19.49% are used. This efficiency is relatively high compared to other solar panels available in the market today.

The equal distribution and spread of solar panel usage or electricity production from other renewable energy sources also significantly impact the reduction of the carbon footprint. Data shows that although electricity production from solar panels in Indonesia is still low compared to other ASEAN countries, it continues to increase yearly. This indicates that the use of coal-generated electricity is gradually decreasing. Consequently, the carbon emissions associated with electricity consumption will also decline over time.

5. CONCLUSION

This study addresses the electricity shortfall in Oelpuah village, East Nusa Tenggara, by proposing the installation of an additional 4 MW solar farm. Through comprehensive feasibility studies, the village was identified as an ideal location due to its high solar radiation levels. Potential risks, including forest fires, floods, landslides, and earthquakes, were assessed to determine the safest and most efficient site for the solar farm. Two potential sites were identified, with site number 2 being selected due to its low forest fire risk, unused land status, and proximity to the road for on-grid electricity distribution. The system design, utilizing PVSyst software, identified optimal solar panel orientation with a 15-degree tilt and a northward 0-degree azimuth to maximize energy production. The proposed solar farm will use 13,500 Seraphim 330 Wp solar panels and seven 500 kW inverters, covering an area of 22,962 m^2. This system is expected to generate 7,855,688 kWh/year, meeting the electricity needs of approximately 4,877 households. Economically, the project is highly viable, with a production cost of 474 rupiah per kWh and a selling price of 3,450 rupiah per kWh. The payback period is estimated to be 2.7 years, with a return on investment (ROI) of 982.3% over 30 years. The solar farm will also significantly reduce carbon emissions, preventing the release of 142,964.344 tons of CO_2 over its 30-year lifespan. In conclusion, the additional 4 MW solar farm in Oelpuah village is a sustainable and economically feasible solution to address the electricity deficit, reduce carbon emissions, and contribute to Indonesia's renewable energy goals. This project could serve as a model for similar initiatives in other regions facing electricity shortages.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Fahmy Rinanda Saputri				✓	✓					✓		✓	✓	✓
David Tee			✓			✓	✓	✓	✓		✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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