# ANALYSIS OF TECHNO-ECONOMIC PLANNING OF ON-GRID ROOFTOP PV SYSTEM AT THE GOVERNMENT HOUSE OF PACITAN REGENCY

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## Abstract

The geographical condition which is relatively difficult to reach, electricity and infrastructure have not been maximized, making the electrification ratio in Pacitan Regency one of the lowest on the island of Java at 65%. Pacitan Regency has a promising renewable energy potential, but it has not been maximized for the benefit of the residents. One of them is a solar power plant. If used properly, this alternative energy source can be a solution to meet energy needs in remote areas.

As part of the Government's efforts to achieve the new and renewable energy (RE) target of 23% by 2025, the Ministry of Energy and Mineral Resources has issued Minister of Energy and Mineral Resources Regulation Number 26 of 2021 concerning Connected Rooftop Solar Power Plants. On the Electric Power Network, the Holder of a Business License for the Provision of Electric Power for Public Interest (IUPTLU). This Ministerial Regulation is a refinement of the previous regulation as an effort to improve the governance and economics of PV, especially PV Rooftop. This regulation is also a step to respond to the existing dynamics and facilitate the public's desire to obtain electricity from renewable energy sources, as well as the desire to contribute to reducing greenhouse gas emissions.

This study was conducted to calculate the optimum potential of rooftop photovoltaic power plants in the official residence of the Pacitan Regency Government as an alternative energy source to supply the electricity system from the official residence. This simulation was carried out using the System Advisor Model (SAM) software by taking into account the technical and economic aspects. Where the economic calculation has 2 scenarios, namely the profit value based on the Minister of Energy and Mineral Resources Regulation No. 26 of 2021 and the Minister of Energy and Mineral Resources No. 49 of 2018 with a total energy produced of 13012 kWh / year with a total of 20 modules installed with a slope of 20° facing north and 1 Inverter and an LCOE value of Rp. 1231.31/kWh and an NPV of Rp. 117,579,325.50.

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## 1. Introduction

Solar energy's potential in Indonesia is quite large, more than enough to meet the Net Zero Emission (NZE) target. Currently, Indonesia is participating in the energy transition program towards Net Zero Emission (NZE) in 2050, so solar energy is one of the mainstays for its achievement. According to records, the potential for solar energy inventoried by the Directorate General of EBTKE is 207 GW. Meanwhile, the calculation results of the Indonesian Renewable Energy Society (METI), the potential reaches 2000 GW, while the calculation from IESR states that Indonesia's solar energy potential reaches 19800 GWp.

In East Java Province, 38 regencies or cities have an electrification ratio of 98.8% in 2020. From the 38 regencies or cities, 17 Regency have not achieved an electrification ratio of 100%, including the Pacitan Regency, which is a 3T area (leading, outermost, and underdeveloped) with the lowest electrification ratio in Java, which is 65%. The electricity consumption in Pacitan Regency is supplied by PT. PLN East Java Distribution through GITET (Gardu Induk Tegangan Extra Tinggi) Kediri. Several sectors consume electricity in Pacitan Regency: household, industrial, business, social, government office buildings, and public street lighting. Total energy consumed in all sectors in the Pacific is 155.432,280 GWh.

According to 2016 Ministerial Regulation No. 38, which contains the business of providing electricity for the 3T area, the potential for new and renewable energy can be utilized to increase the electrification ratio in the local area, considering that access is quite difficult to reach The challenges faced in providing electricity to Pacitan Regency is developing a new renewable energy-based power plant to maximize the use of new renewable energy sources that can produce electrical energy in the local area so that the electrification ratio of Pacitan Regency is expected to increase and support the development of the area.

Urban areas are densely built, so they must be careful in utilizing renewable energy. Urban areas have narrow land, so they utilize solar energy by using solar modules as an alternative to obtaining electrical energy by utilizing roofs on buildings (Hanna, 2012). One sector that utilizes energy in the building sector consumes up to 40% of the total global annual energy consumption (UNEP, 2009). Solar energy has the potential to be developed in Indonesia because Indonesia is located on the equator. The entire landmass of Indonesia, which has an area of 2 million km$^2$, can generate solar energy of 4.8 kWh/m$^2$/day, equivalent to 112,000 GWp (Hasan, 2012).

The Pacitan Regent's Office Building is located in the middle of Pacitan City. The Government itself has a plan for the construction of a PV Rooftop, but what is still being considered is that there is no in-depth study related to the use of PV Rooftop in Pacitan Regency itself. It is necessary to conduct an in-depth analysis of the PV system, so a PV system design is carried out using the rules that follow the optimal PV installation. This research is one of the studies in the field of Systems Engineering where this research does discuss not only the technical side but also the economic side.

## 2. Methodology

a. Data Collection

The research material uses primary and secondary data, as shown in Table 1. Primary data includes building area and energy consumption, and secondary data is sunlight intensity data and component specifications. The data is collected collectively in government agencies, academia, and business, which correlates with the researchers.

Table 1. Data Research

| No | Data | Data source |
|---|---|---|
| 1 | Electricity Bill Data | Pacitan Home Office Electricity Bill Recap |
| 2 | Sunlight Intensity | Metonorm, Literature Study |
| 3 | Building Area | Public Works Department for Taba Pacitan |
| 4 | Component Specification | Study of literature |
| 5 | Economic Scenario | Bank Indonesia, Electricity Bill |

Weather data was used in this study using Meteonorm software. This data will later be used as input in simulating Techno-Economics in the System Advisor Model (SAM) software. Weather data can be seen in Table 2:

Table 2. Pacitan Regency Weather Data

| Month | Solar Radiation ($kWh/m^2$/hari) | Temperature (°Celcius) |
|---|---|---|
| Jan | 5,40 | 26 |
| Feb | 5,17 | 25,9 |
| Mar | 5,80 | 26,3 |
| Apr | 5,73 | 26,8 |
| May | 5,40 | 27 |
| Jun | 5,17 | 26,4 |
| Jul | 5,47 | 26 |
| Aug | 5,87 | 25,9 |
| Sep | 5,93 | 26,5 |
| Oct | 6,53 | 27,2 |
| Nov | 5,70 | 27 |
| Dec | 6,13 | 26,3 |
| Average | 5,69 | 26,44 |

PV Out generated for Pacitan Regency is 4,158 kWh/kWp/day. The total consumption in Figure.1 is the electrical energy produced by the Pacitan Regency Municipal Housing in 2021 at 7570 kWh. High energy consumption occurs because the load used is many resistant loads such as AC and lights.

In this study, the research methodology aims to solve the existing problems structured. The following division of the research flow chart is shown in Figure 2.

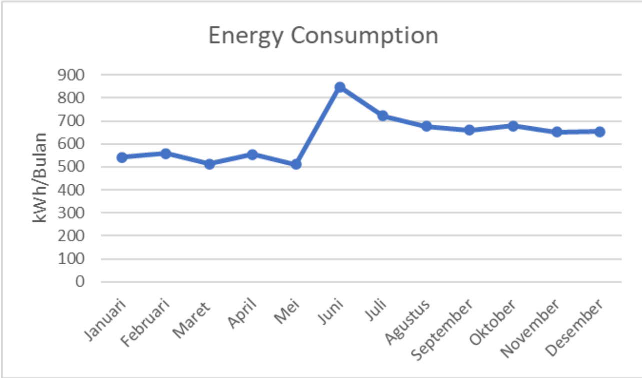



Figure 1. Energy Consumption Chart 2021

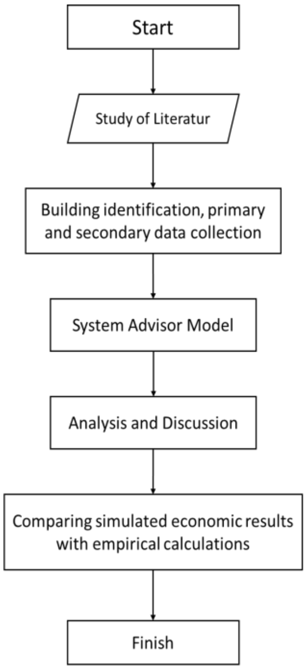



Figure 2. Research Flowchart

b. Building Model

The Pacian Regent's official house is a government agency building. The building is located on Jl. Attorney General Suprapto No. 8, Krajan, Pacitan, Kec. Pacitan, Pacitan Regency, East Java. The Pacitan Regent's Official House is located at coordinates -8.192120845701078, 111.10346858465448.

For modeling, the PLTS is placed on the rooftop of the Pacitan Regent office building at an angle of 20° facing north. Figure 3 shows a 3D model of the Pacitan Regency Regent's official house building.

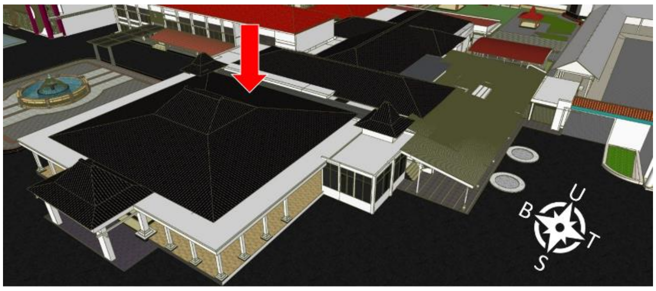



Figure 3. Building Model

c. Economic Model

Several other indicators commonly used to determine the calculation of the economic feasibility of a system are Net Present Value (NPV), Levelized Cost of Energy (LCOE), and Payback Period (PP).

I. Net Present Value (NPV)

Net present value (NPV) is a value that indicates the amount of money generated from a system investment. NPV is calculated by summing all cash flows over the period from zero or so-called negative investment to the end of the period (Yusuf, 2016).

$$NPV = \sum_{i=0}^{n} \frac{NFC_t}{(1-i)^t} - \mathrm{II}$$

*NPV* = Net Cash Flow 1st to n year period
*II* = Initial Investment
*I* = Discount rate
$n$ = Period in years (life of investment)

II. Levelized Cost of Energy (LCoE)

Levelized cost of electricity (LCOE) is the price of electrical energy generated from a particular energy source and can reach the break-even point even within a particular time period. This period is determined based on the life of the power generation system (Kost, 2013).

$$LCOE = \frac{\sum_{t=1}^{n} \frac{It + Mt + Ft}{(1+r)^t}}{\sum_{t=1}^{n} \frac{Et}{(1+r)^t}}$$

*LCOE* = Average lifetime cost for generator
*It* = Investment cost in year-t
*Mt* =Operational and maintenance costs in year-t
*Ft* = Fuel cost in year-t
*Et* = Total electrical energy generated in year-t
$r$ = Discount rate
$n$ = Generator service life

III. Payback Period (PP)

Payback Period (PP) is a parameter used to calculate how fast it takes to return a system investment (Sugirianta dkk, 2017).

$$PP = \frac{Initial\ investment}{net\ cash\ periodic\ receipts}$$

d. System Advisor Model

The System Advisor Model (SAM) was developed by the National Renewable Energy Laboratory (NREL) by the United States Department of Energy, as shown in Figure 4. The System Advisor Model (SAM) is a techno-economic software model designed to facilitate decision-making for people in the renewable energy industry, such as project management, financial and policy analysis, technology developers, and researchers (NREL, 2018). The System Advisor Model (SAM) makes performance predictions and energy estimates for electricity projects connected to the grid (on-grid), one of which is the Solar Power Plant.

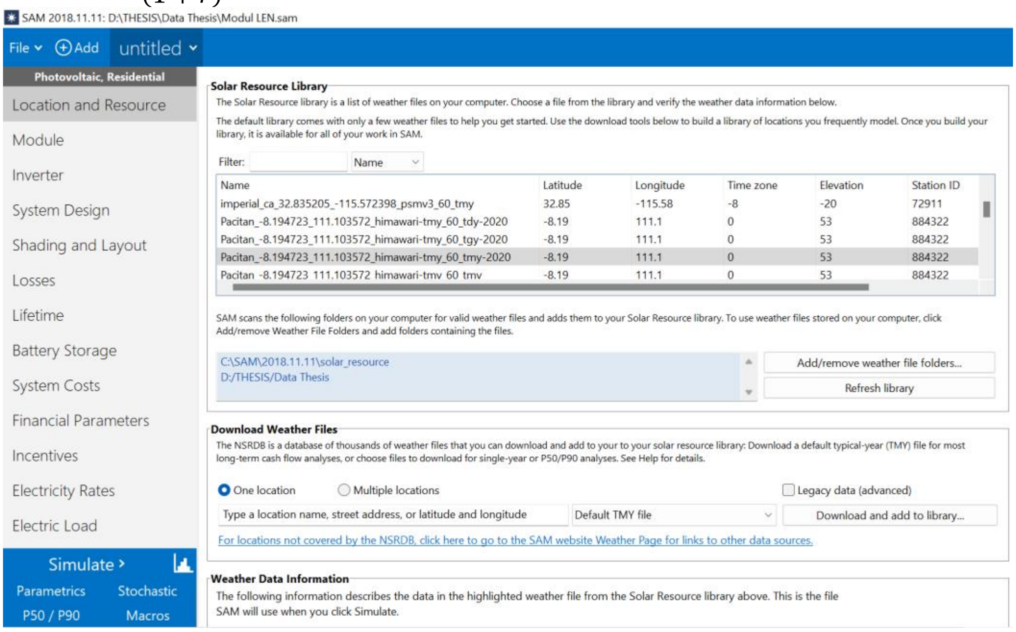


Figure 4. Software System Advisor Model

## 3. Results & Discussion

a. PV Technology

From the data above, the simulation of the PV roof plan is carried out using the System Advisor Model software using the On-Grid system by comparing the investment value of the Off-Grid system. The PV system was chosen because it reduces the electricity supply from PLN and Operation and Maintance (O&M) costs and the value of the initial investment. PV is planned to use a panel type with polycrystalline technology.

Specifications of solar panels and inverters used in planning the Pacitan Regent's Pendopo Building are shown in Tables 3 and 4.

Table 3. Canadian Solar CS 1U-400W Solar Panel Specifications

| Characteristics | Value | Unit |
|---|---|---|
| Nominal Max. Power (Pmax) | 400 | Watt |
| Opt. Operating Voltage (Vmp) | 44,1 | Volt |
| Opt. Operating Current (Imp) | 9,08 | Ampere |
| Open Circuit Voltage (Voc) | 53,4 | Volt |
| Short Circuit Current (Isc) | 9,60 | Ampere |
| Modul Efficiency | 19,4 | % |
| Operating Temp | ~40 - (+85) | Celcius |
| Max. System Voltage | 1500 | Volt |
| Max. Series Fuse Rating | 15 | Ampere |
| Application Classification | Class A | |
| Power Tolerance | 0 - 10 | Watt |

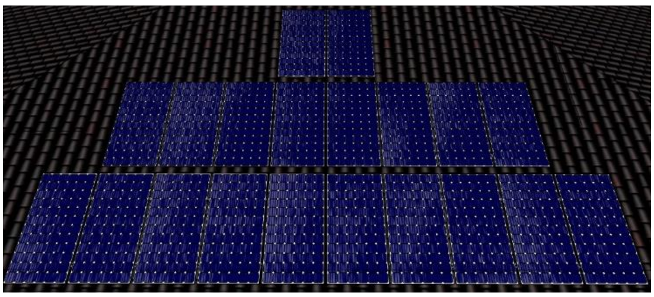
Pacitan Regency Hall has an installed Grid capacity of 66.000 VA. Based on Minister of Energy and Mineral Resources No. 26 of 2021, the PV capacity produced is the same as the installed grid capacity. So with the above panel specifications, the required modules for designing PV mini-grid roofs are 20 PV modules.

Table 4. Specifications of SMA America SB6.0 Inverter (240)

| Characteristics | Value | Unit |
|---|---|---|
| Input DC | | |
| Max. DC Power | 9600 | Wattpeak |
| Max. Input Voltage | 600 | Volt |
| Rated MPP Voltage Range | ~220 - 480 | Volt |
| MPPT Operating Voltage range | 100-55 | Volt |
| Max Operating Input current per MPPT | 10 | A |
| Output AC | | |
| AC Nominal Power | 6000 | Wattpeak |
| Max. Ac Apparent Power | 6000 | VoltAmpere |
| AC Voltage Range | 211-264 | V |
| Power Factor | 1 | |
| Efficiency | 97,7 | Percent |

b. Simulation

In this simulation, PV will be applied to the roof of the northern part of the Pacitan Regency Official House with a slope of 20° facing north. Details of the 3D PV Roof can be seen in Figure 5.



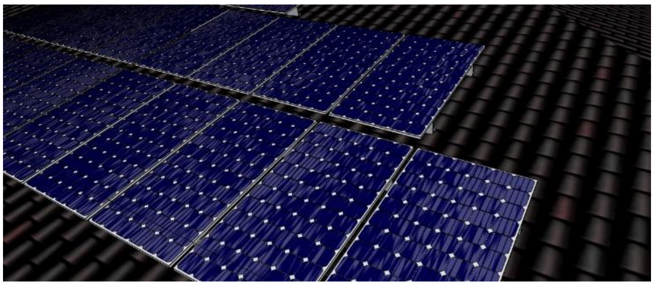


Figure 5. Position and Placement PV

PV system planning analysis is simulated using the On-Grid System. This is done because the On-Grid system is a simple PV system and very cost-effective, unlike the Off-Grid PV system, which usually costs quite a bit because the battery price is relatively high.

The simulation in Table.4 uses 20 PV panels connected in series and parallel with a roof area of 40 $m^2$. The total energy produced in 1 year is 13.012 kWh. The total energy produced exceeds the total load in 1 year, which is 7.570 kWh.

Table 4. System Simulation Results

| Metric | Value | Unit |
|---|---|---|
| Annual energy (year 1) | 13.012 | kWh |
| Capacity factor (year 1) | 18,6 | % |
| Energy yield (year 1) | 1.626,0 | kWh/kW |
| Performance ratio (year 1) | 0,8 | |
| Levelized COE (nominal) | 1.231,31 | Rp/kWh |
| Levelized COE (real) | 936,24 | Rp/kWh |
| Net present value | 117.579.325,50 | Rp |
| Simple payback period | 8,7 | Year |
| Discounted payback period | 11,5 | Year |
| Net capital cost | 187.523.949,90 | Rp |
| Debt | - | Rp |

Figure 6 explains that the monthly PV production is directly proportional to the load used. From October to November, there is a decrease in energy production from PV, which is influenced by radiation, temperature, and module orientation, so the energy results obtained are less than optimal. The graph above can also calculate monthly PV production with an average energy savings of 1,084.35 kWh/month.

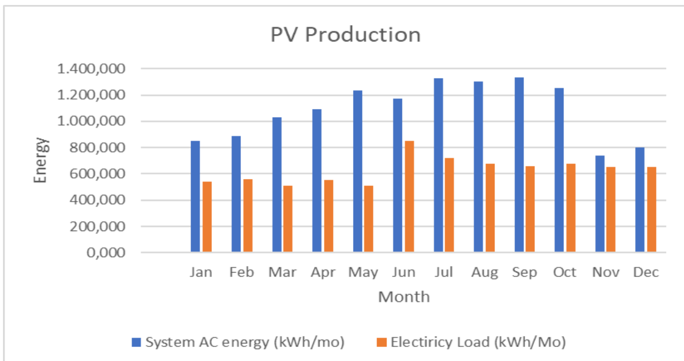



Figure 6. PV Production Graph

The comparison of investment in on-grid and off-grid systems is shown in Tables 4 and 5.

Table 4. On-Grid Rooftop PV System Component Cost

| Details | Amount | Price (Rp) | Total (Rp) |
|---|---|---|---|
| Module | 20 | 2.506.636 | 50.132.723 |
| Inverter | 1 | 17.904.072 | 17.904.072 |
| Initial capital | | | 53.384.316 |
| BOS | | | 22.620.453 |
| Installation fee | | | 18.096.305 |
| Total | | | 162.137.870 |

In investment modeling for PV, the price of PV components adjusts to the prices prevailing in Indonesia (rupiah), where the rupiah exchange rate prevailing in Indonesia during 2022 is an average of Rp. 14,356 for 1 dollar with 2.68% inflation and 3.5% interest rate. The operational and maintenance costs of the PV system are calculated annually at 1% - 3% of the total initial investment cost (IRENA, 2011).

Table 5. Off-Grid Rooftop PV System Component Cost

| Details | Amount | Price (Rp) | Total (Rp) |
|---|---|---|---|
| Module | 20 | 50.132.723 | 50.132.723 |
| Inverter | 1 | 17.904.072 | 17.904.072 |
| Initial Capital | | 53.384.316 | 53.384.316 |
| BOS | | 22.620.453 | 22.620.453 |
| Installation fee | | 18.096.305 | 18.096.305 |
| Battery | 9 | 57.058.275 | 57.058.275 |
| Total | | | 219.196.144 |

The initial investment value for the On-Grid PV system at the Pacitan Regency Official House is Rp. 162,137,870.06, and this amount is much smaller when compared to the Off-Grid system, which is Rp. 219,196,144.94 with the same service life of about 25 years. This means that the On-Grid PV system planning at the Kab. Pacitan deserves to be realized. The plan's feasibility can be seen in Table 4, where the LCOE obtained is IDR 1,231.31/kWh. This cost is cheaper than the purchase price of electricity from the network, which is Rp. 1444.7 /kWh.

In contrast to the Off-Grid LCOE system, the amount obtained is Rp. 1,755.45/kWh. This cost is higher than the purchase price of electricity from the network, which is Rp. 1444.7 /kWh. The NPV value in the simulation carried out is positive, namely Rp. 89,641,673.80, which means if the NPV is positive, then this project is feasible to be realized with a payback period on the On-Grid system for 8 years and the Off-Grid system for 12 years.

c. Economic Analysis Based on the Minister of Energy and Mineral Resources

On August 13 2021, the Minister of Energy and Mineral Resources issued a Ministerial Decree concerning Rooftop Solar Power Plants Connected to the Electric Power Network. 49 of 2018 to no. 26 of 2021. This change significantly impacts the buying and selling of electricity (Export-Import). The Exim System on the PV Rooftop, applied to the Pacitan Regency Official House.

The electrical energy of the exported PV Rooftop at Pacitan Pavilion is calculated based on the export kWh value. Where the difference in the export-import value is multiplied by 65%, the total cost of incentives in 1 year is Rp. 5,110,585 according to the ESDM Ministerial Decree no. 49 Years 2018. However (Table 6), in the ESDM Ministerial Decree no. 26 Years 2021 multiplied by 100% means that it is back to back, the total cost of incentives in 1 year is Rp. 7,862,439 (Table 7). Tables 6 and 7 show the percentage of the new regulations related to the value of import exports provides a significant advantage where this goal provides an attraction for PLTS Roof users. In the Planning of PLTS Roofs Pacitan Regency Offices, the percentage of profits from export-import incentives is 61% for the Minister of Energy and Mineral Resources. No. 26 of 2021 and 39% for the Minister of Energy and Mineral Resources No.49 of 2018.

Table 6. Export-Import Incentive Value ESDM Ministerial Decree no. 49 Years 2018

| No | Month | Energy Produced by PV (kWh/Mo) | Energy From PLN (kWh/Mo) | Difference | Incentive (kWh/Mo) |
|---|---|---|---|---|---|
| 1 | January | 848,067 | 542 | 306,067 | Rp 287.414 |
| 2 | February | 888,084 | 559 | 329,084 | Rp 309.028 |
| 3 | March | 1029,32 | 513 | 516,32 | Rp 484.853 |
| 4 | April | 1089,17 | 555 | 534,17 | Rp 501.615 |
| 5 | May | 1234,82 | 510 | 724,82 | Rp 680.646 |
| 6 | June | 1170,44 | 848 | 322,44 | Rp 302.789 |
| 7 | July | 1328,66 | 723 | 605,66 | Rp 568.748 |
| 8 | August | 1301,19 | 677 | 624,19 | Rp 586.149 |
| 9 | September | 1331,17 | 660 | 671,17 | Rp 630.266 |
| 10 | October | 1251,34 | 679 | 572,34 | Rp 537.459 |
| 11 | November | 740,227 | 651 | 89,228 | Rp 83.790 |
| 12 | December | 799,775 | 653 | 146,775 | Rp 137.830 |
| Total | | 13012 | 7570 | 5442 | Rp 5.110.585 |

Table 7. Export-Import Incentive Value ESDM Ministerial Decree no. 26 Years 2021

| No | Month | Energy Produced by PV (kWh/Mo) | Energy From PLN (kWh/Mo) | Difference | Incentive (kWh/Mo) |
|---|---|---|---|---|---|
| 1 | January | 848,067 | 542 | 306,067 | Rp 442.175 |
| 2 | February | 888,084 | 559 | 329,084 | Rp 475.428 |
| 3 | March | 1029,32 | 513 | 516,32 | Rp 745.928 |
| 4 | April | 1089,17 | 555 | 534,17 | Rp 771.715 |
| 5 | May | 1234,82 | 510 | 724,82 | Rp 1.047.147 |
| 6 | June | 1170,44 | 848 | 322,44 | Rp 465.829 |
| 7 | July | 1328,66 | 723 | 605,66 | Rp 874.997 |
| 8 | August | 1301,19 | 677 | 624,19 | Rp 901.767 |
| 9 | September | 1331,17 | 660 | 671,17 | Rp 969.639 |
| 10 | October | 1251,34 | 679 | 572,34 | Rp 826.860 |
| 11 | November | 740,227 | 651 | 89,228 | Rp 128.908 |
| 12 | December | 799,775 | 653 | 146,775 | Rp 212.046 |
| Total | | 13012 | 7570 | 5442 | Rp 7.862.439 |

## 4. Conclusion

Some essential points can be summarized from the finding of the research as follow:

1. Simulation of the PLTS Roof Design at Pacitan Pavilion using a system advisor model using 20 modules of solar modules with polycrystal technology (16% efficiency) and 1 SMA America SB6.0 (240) inverter with a service life of 25 years. The PLTS design simulation produces an optimal value with the position of the solar module facing north with a slope of 20$^{o}$.

2. The simulation results with the On-Grid system using 20 PV panels with a roof area of 40 $m^2$, produced in 1 year of 13,012 kWh. The total energy produced exceeds the total need in 1 year, which is 7.570 kWh.
3. The total investment cost for the On-Grid system is Rp. 162,137,870.06 with an LCOE value of Rp. 1,231.31 /kWh and the resulting NPV value is Rp. 117,579,325.50. The NPV value is more than 0 or positive, and the payback period value in the PLTS system occurs in the 8th year. The value generated by the On-Grid system is smaller than the total investment cost of the Off-Grid system of Rp. 219,196,144.94 with an LCOE value of Rp. 1755.45/kWh and the resulting NPV value is Rp. 29,875.772.45. The NPV value is more than 0 or positive, and the payback period in the PLTS system occurs in the 12th year. Based on the calculation of LCOE, NPV, and Payback Period, the on-grid system is more feasible to invest in because it is more profitable.
4. The incentives obtained from the Exim score are based on the latest ESDM candy. The ESDM candy no. 26 in 2021 is much more profitable because the export-import value is already 100%, meaning that what we use is the same as what we sell.

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