

# TECHNO- ECONOMIC ANALYSIS OF SOLAR POWER PLANT SYSTEMS TO REALIZE SUSTAINABLE DEVELOPMENT GOALS (SDGS)

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## Keywords

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## Abstract

Energy issues related to global warming, the environment, and energy flows are socio-economic challenges in the demand for electrical energy. The demand for electrical energy will increase by around 11-12% in 2025 and 6-7% by 2050 with the Indonesian State Electricity Company being the primary supplier of electrical energy which is mostly sourced from fossil fuels. Applying renewable energy is a solution to reducing dependence on fossil fuels. This study analyzes the technical and economic feasibility of a 46 kWp Solar Power Plant in Beloh village by utilizing PVsyst software. This hybrid system uses 184 solar panels with a capacity of 250 Wp, 2 units of 20 kW inverters, and 224 units of 100 Ah batteries. The results showed that the system output power is 189.25 kWh per day or 69077 kWh/year which will supply the load of 40 houses of 166.82 kWh/ day. In realizing the SDGs, solar power plants can apply SDG 7 with a Performance Ratio (PR) value of 75.7%, SDG 9 regarding industry, innovation, and infrastructure, SDG 11 related to sustainable cities and human settlements. This solar power plant is very environmentally friendly and can reduce carbon dioxide emissions by 1118 tons/25 years. This designed solar power plant system is accompanied by an economic analysis of Net Present Value (NPV) amounting to IDR 404,631,838. Payback Period in the 9th year, Break Even Point (BEP) achieved in the 8th year, and Return on Investment (ROI) of 215%.

## 1. Introduction

The utilization of New Renewable Energy is currently the focus of world development. This research is expected to be able to face the challenges of planning the best products that focus on the field of renewable energy for energy-independent homes and energy management. Currently, the energy-independent housing and energy management program is one form of utilizing and optimizing renewable energy to achieve the Sustainable Development Goals (SDGs).

Currently, the issue of energy use and supply, driven by global warming and environmental challenges, creates various socio-economic challenges that are increasingly urgent (Salim et al., 2018). If humans want to achieve more promising, brighter energy with reduced environmental, economic, and social impacts, then this challenge needs to be addressed together. One of them is through the targets of the 17 SDGs, namely, clean and affordable energy. The impact of this target can certainly be seen in the increasing number of renewable energy development phenomena, one of which is solar power plants as an alternative energy source to meet electrical energy consumption (Bertheau, 2020; Leal Filho et al., 2021)

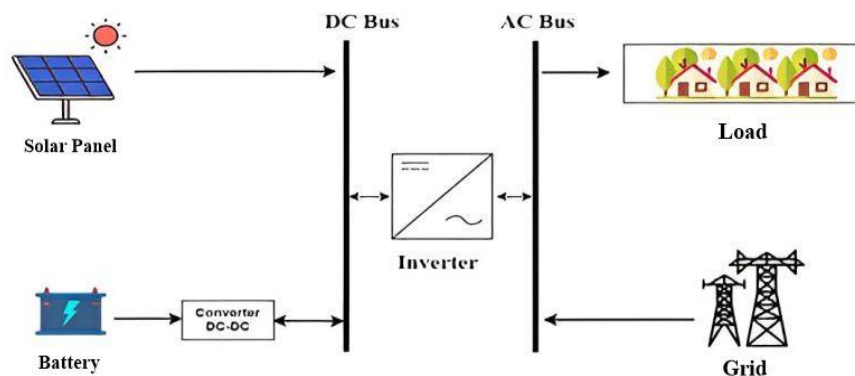


Research on the feasibility of a solar power plant in Saudi Arabia by Rehman led to the design of a 10 MW grid-connected solar power plant. The Bisha area in Saudi Arabia was selected for the installation due to its highest solar radiation intensity and longer sunlight duration (Rehman et al., 2017). Meanwhile, Obeng's research indicates that building a solar power plant with three different PV models results in annual electrical energy exports of 67315 MWh, 67506 MWh, and 68991 MWh. The NPV is positive, and the cost ratio exceeds 1.0, with payback periods of 7.2 years for the crystalline silicon system and 6.4 years for the thin-film system (Obeng et al., 2020). Additionally, Ray's study analyzed the economic viability of an 80 kWp solar power plant producing 89.83 MWh annually, with an NPV of IDR 81.346.406 and an IRR of 0.54% (Ray et al., 2021). Dekkiche's research found that the optimal design of a PV/RF hybrid system connected to the grid yielded the best economic performance, with low NPC and COE, a positive ROI, and the shortest simple payback period of 7.79 years (Dekkiche et al., 2023). Lastly, Peprah's research involved building a solar power plant using RET screen design and simulation, focusing on the best investment options, including grid integration without storage (2023)

Based on the above references, this research will focus on the techno-economic analysis of a 46 kWp hybrid solar power plant system to achieve the Sustainable Development Goals (SDGs).

### 3. Research Methods

The solar power plant system discussed in this research is a centralized hybrid system with a capacity of 46 kWp. This solar power plant consists of several components, such as solar panels, batteries, and inverters. The hybrid system is shown in Figure 1.



**Fig. 1 - solar power plant system schematic**

Solar panels function to convert solar radiation into electrical energy. The electrical energy produced by the solar panels will be reduced in voltage by a DC-DC converter so the battery can be charged. Then the electrical energy from the battery will flow to the inverter to be converted from DC to AC, and, through the inverter, it is distributed. Electrical energy will be distributed to the load via the Main Distribution Panel (MDP) and electric pole cables, which serve each house. When the electrical energy from the solar module and battery is insufficient to supply the load, it will be manually switched to the electricity grid.

This research uses data visualization to process the data. The data in this research were visualized using PVsyst software. The MATLAB application will reprocess data that cannot be displayed in PVsyst. The experimental scenarios in this research are as follows. The first scenario is a direct technical calculation using existing equations. The second scenario is that the calculation results and data obtained will be simulated in PVsyst software, and economic calculations will be performed directly using existing equations. Data and calculation results that cannot be presented in PVsyst will be processed in MATLAB, and then technical and economic analyses will be carried out based on the simulation results.

### 3.1. Technical analysis

#### 3.1.1. Solar Radiation Intensity

Solar radiation intensity is the amount of energy received by a surface per unit of time. The intensity of solar radiation at the research location was obtained through the Meteonorm database. Solar radiation data is used to evaluate the solar energy potential at the research location.

#### 3.1.2. Daily Load

Electrical load data from the research location are needed to estimate the capacity of the solar power plant to be built. Daily energy calculations are obtained using the following equation.

$$W_{Supply} = (SF \times W_{demand}) + W_{demand}$$

#### 3.1.3. Solar Power Plant

After estimating the daily energy at the research location, the next step in designing the solar power plant is calculating the peak power and the solar power plant energy. To calculate the peak power of a solar power plant, you need to pay attention to the power losses in the PV module. To find out the power and energy produced by solar power plants, it can be calculated using equation 2 as follows

$$P_{solar\ power} = \frac{W_{Supply}}{PSH} + (15\% \times \frac{W_{Supply}}{PSH})$$

#### 3.1.4. Solar Power Plant Components

After estimating the load requirements, the next step in planning the solar power plant design is calculating the components to be used. These components comprise of PV modules, batteries, and inverters (Liu et al., 2021; Tayagaki et al., 2021).

Calculation of PV amount

$$N_{PV} = P_{solar\ power} / P_{PV}$$

Inverter Calculation

$$P_{INV} = P_{Demand} + (SF \times P_{Demand})$$

$$N_{INV} = \frac{P_{INV}}{P_{single\ INV}}$$

#### 3.1.5. Potential Solar Energy Received by Panels

Analysis of the potential solar energy received by the panels is obtained from graphs generated by the PVsyst software simulation. The amount of electrical energy produced by the PV system is also needed to determine the system's energy output, so the next step in technically analyzing the solar power plant is to review the system's daily energy output using graphs of PVsyst simulation results.

#### 3.1.6. Energy Production per Installed kWp

In designing a solar power plant, it is necessary to know the system's output power. This aims to find out how much the system that has been designed can produce energy and can supply the load at the research location, so the next step is to analyze the system output results obtained through graphs from the PVsyst software simulation

#### 3.1.7. System Efficiency

The efficiency of a solar PV system is the extent to which it converts solar energy into electrical energy. The next step is to evaluate the PVsyst simulation results for the solar power plant's efficiency.

### 3.1.8. Sustainable Solar Power Plant System in Realizing SDGs

The sustainability of the solar power plant system can be seen from the resulting performance ratio, which should be within the ideal range of 70% - 90% (Hariyati et al., 2019). After assessing the sustainability of the system, an analysis is conducted of other SDG targets aimed at achieving the SDGs.

### 3.1.9. CO2 Gas Emissions

To calculate the CO2 (eCO2) gas emissions that can be reduced by using solar power plants for 25 years. The project life can be determined and adjusted to the longest component life (Chambers, 1995). To calculate CO2 gas production, you can use the following equation.

$$e_{CO_2} = energi\ harian \times ef$$

## 3.2. Economic Analysis

Reference refers to the UMR at the research location. In carrying out an economic analysis, the next step is to calculate operational costs, which in the research are calculated at 1% of the initial investment costs through equation 9 (Akbar et al., 2023; Hajar & Sara, 2022; Tian et al., 2019)

$$CO = 1\% \times \text{Initial investment costs}$$

Furthermore, additional maintenance costs can be calculated using equation 10.

$$C_{oM} = \text{Initial investment costs} / 25 \text{ years}$$

To determine the COE of a microgrid system, use the following equation.

$$CRF(\%) = \frac{i(1+i)^n}{(1+i)^n - 1}$$

$$COE = \frac{C \times CRF}{\sum_{d=1}^{365} W_{annual}}$$

When analyzing a project economically, it is necessary to understand the project's cash flow. The annual income is obtained through equation 13.

$$I = W_{Annual} \times TL$$

### 3.2.1. Net Present Value (NPV)

NPV is an economic parameter considered in this research. The NPV can be calculated using equation 14 (Abdelhady, 2021; Duman & Güler, 2020; Lu et al., 2021; Nicita et al., 2020; Wang et al., 2020).

$$NPV = -C_0 + \frac{C_1}{(1+r)^1} + \frac{C_2}{(1+r)^2} + \dots + \frac{C_t}{(1+r)^t}$$

### 3.2.2. Payback Period (PP)

In the economic analysis of a project, it is necessary to consider the length of the return on capital from an investment (Ozcan & Ersoz, 2019). To calculate PP, you can use equation 15.

$$PP = \frac{n+(a-b)}{(c-b)} \times 1 \text{ Year}$$

### 3.2.3. Break Event Point (BEP)

BEP in economic analysis is used to determine the break-even point of an investment. BEP is calculated using equation 16 (D'Adamo et al., 2019; Maruta, 2018).

$$BEP = \left( \frac{FC}{COE - VC} \right)$$

### 3.2.4. Return on Investment (ROI)

ROI in economic analysis measures the effectiveness and profitability of an investment. ROI is calculated using equation 17 (D'Adamo et al., 2019; Kousky et al., 2019; Maruta, 2018; Ozcan & Ersoz, 2019).

$$ROI = \frac{NP}{C} \times 100\%$$

## 4. Results and Discussion

### 4.1. Existing Condition of Beloh Hamlet

Beloh Hamlet is located in the Mojokerto district. Based on data from the Global Solar Atlas, this area has a latitude of 7.5578°S and a longitude of 112.4°E. Based on electricity load data in Beloh Hamlet with 40 heads of families, there are 40 houses with daily energy of 166,820 Wh or 166.82 kWh. In this area, PT. PLN still supplies the overall daily electricity needs 24 hours a day.

### 4.2. Technical Analysis

#### 4.2.1. Solar Radiation Intensity

It can be obtained from the Metronom database in PVsyst to determine solar radiation intensity in the research area. Figure 2 explains the data on the intensity of solar radiation in Beloh Hamlet.

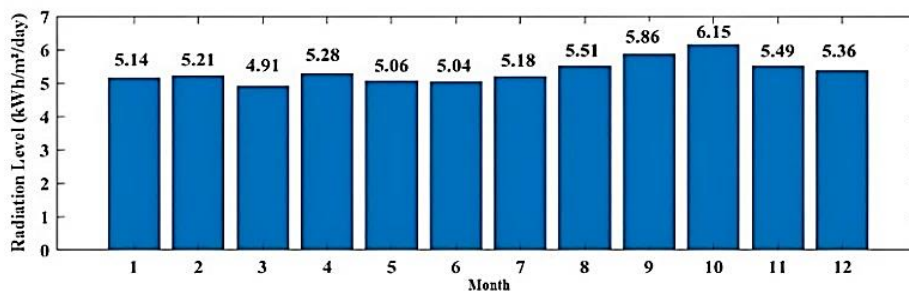


Fig. 2 – Solar Irradiation Intensity

Based on Figure 2, the maximum radiation intensity is in October at 6.15 kWh/m<sup>2</sup>/day and the minimum is in March with an intensity of 4.91 kWh/m<sup>2</sup>/day. The average solar radiation at the research location from January to December is 5.35 kWh/m<sup>2</sup>/day.

#### 4.2.2. Daily Load

Based on Figure 3, the peak power at this research location is 12,000 W at 19.00 – 21.00, and the minimum load power is 3860 W at 08.00 – 09.00 and 15.00.

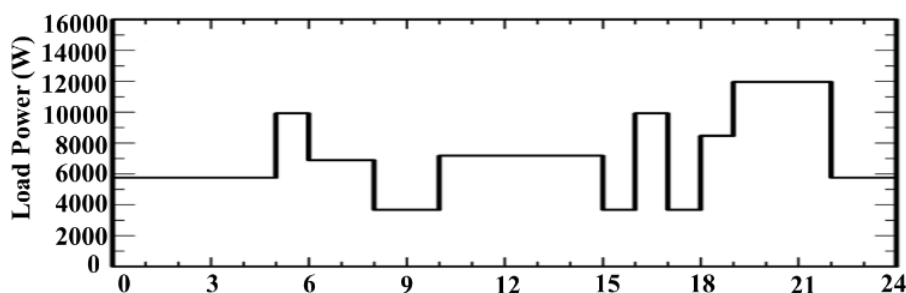


Fig. 3 – Beloh Hamlet's Daily Load

**Table 2. Load Data**

| Load             | Amount | Power [W] | Time [Hour] | Daily energy [Wh] | Pdemand [W] |
|------------------|--------|-----------|-------------|-------------------|-------------|
| Lamp (LED/ Fluo) | 208    | 10        | 10          | 20800             | 2080        |
| TV/PC/Mobile     | 36     | 75        | 4           | 10800             | 2700        |
| Peralatan Rumah  | 25     | 250       | 2           | 12500             | 6250        |
| Tangga           | 32     | 115       | 24          | 88320             | 3680        |
| Mesin cuci       | 10     | 320       | 2           | 6400              | 3200        |
| Kipas Angin      | 35     | 100       | 8           | 28000             | 3500        |
| Total            | 346    | 870       | 50          | 166820            | 21410       |

Based on the load data above, with a 25% safety factor as a reserve in case of additional load (Aul et al., 2022), we obtain the daily energy requirement (*Wsupply*) of 208525 Wh using equation 1.

### 4.2.3. Solar Power Plant Peak Power

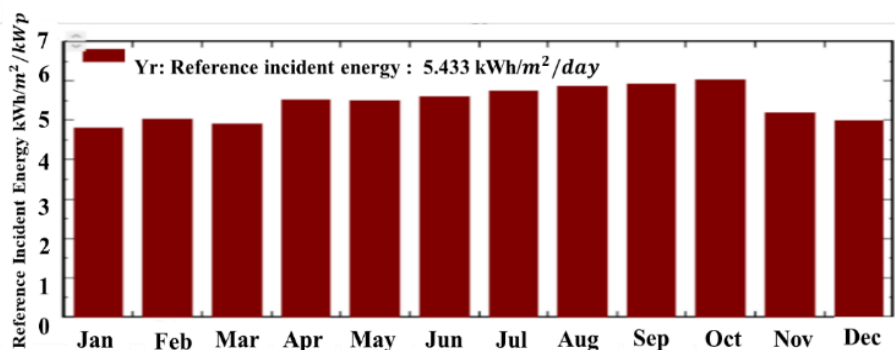
Based on equation 2, with an average irradiance (PSH) of 5.35 kWh/m<sup>2</sup>/day and power losses (*Plosses*) assumed to be 15% because all components are new, the solar power plant's peak power is 46 kWp.

### 4.2.4. Solar Power Plant Components

The main components of a solar power plant consist of solar modules, inverters, and batteries. Based on equation 3, the number of solar modules required for a solar power plant with a capacity of 46 kWp is 184 units connected in series and parallel. There are 8 strings of solar panels connected in parallel, each consisting of 23 solar panel units. The PV type used is monocrystalline, 250 Wp. The reason for choosing this type of monocrystalline module is that it can operate in cloudy weather and has a high electron-absorption capacity. Next, using equations 4 and 5, assuming a safety factor of 20% (Aji et al., 2021), a 46 kWp solar power plant requires 2 units of 20 kW inverters. Next, to calculate the battery requirements for a solar power plant with a capacity of 46 kWp, the battery requirements are obtained using equations 6 and 7, yielding a total of 224 units. The 100 Ah battery from the CS Power Brand was chosen because it has a fairly high efficiency of 97%.

### 4.2.5. Potential Solar Energy Received by Panels

Based on graphic image 4, the average solar energy received by the panels is 5,433 kWh/m<sup>2</sup>/day. The maximum solar energy received by the panel is 6.02 kWh/m<sup>2</sup>/day, which occurs in October, and the minimum is 4.81 kWh/m<sup>2</sup>/day in January.



**Fig. 4 - Reference Incident in Collector Plane**

Figure 5 displays a graph of the global incident count. plane with solar energy available for conversion to electrical energy, the output of the graph should be a slightly saturated straight line for large radiation values. In the graph, you can see a slight curve that shows the effect of temperature.

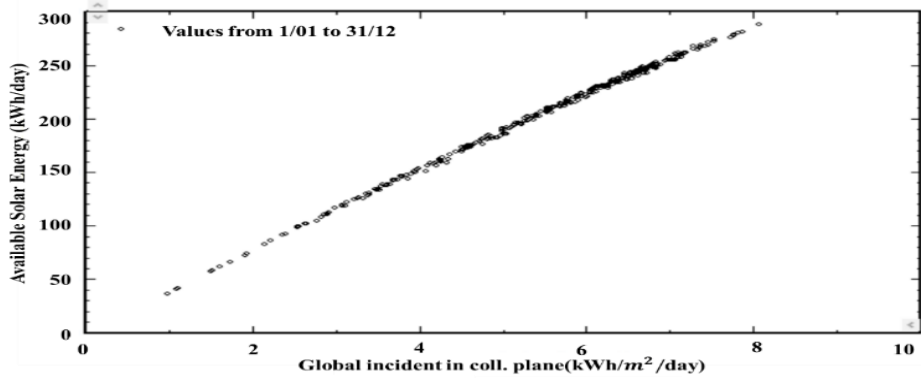


Fig. 5 - Daily Input/Output Diagram

In Figure 6 below, it is shown that the minimum temperature is 21.4°C with a total energy of 10.1 W/m<sup>2</sup> and the highest temperature reaches 76°C with a total energy of 1101 W/m<sup>2</sup> with the average amount of energy produced in a year being 458.9 W. /m<sup>2</sup>.

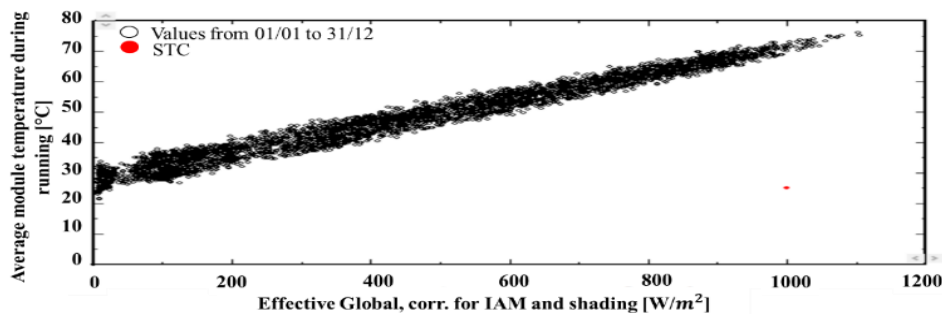


Fig. 6 - Array Temperature vs. Effective Irradiance

In Figure 7, the PV system output ranges from 200W to 1100W, with an average of 5600W. However, the power distribution also indicates that the majority of the system's operating time is at an energy output of 400W-800W. This can be recorded as a leak from the PV system.

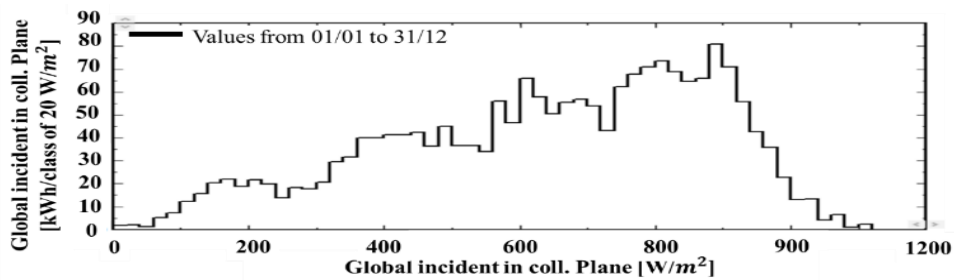


Fig. 7 - Incident Irradiance Distribution

#### 4.2.6. Energy Production per Installed kWp

Based on the simulation results in Figure 8, the output power of a hybrid solar power plant system with a capacity of 46 kWp after power losses is 189.25 kWh per day or the equivalent of 69077 kWh/year which is able to supply a load in Beloh Hamlet, Mojokerto Regency of 166.82 kWh/day. Using the average electricity usage of a 1-story AC house in Indonesia of 1.1 kW, the solar power plant system output power of 189.25 kWh is equivalent to the electricity of around 7 1-story AC houses. The simulation results also show that the energy supplied to the load (Yf) is an average of 4.4 kWh/kWp/day with different power production each month. This difference is also due to the calculation of the global average level of radiation in each month which is different. Power losses in PV (Lc) average 0.94 kWh/kWp/day, and system losses (Ls) amount to 0.09 kWh/kWp/day.

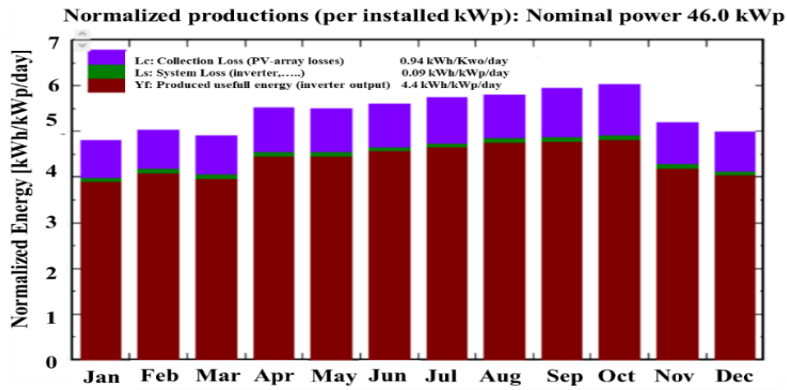


Fig. 8 -Normalized Productions

#### 4.2.7. System Efficiency

In Figure 9 performance ratio [33]-[34].

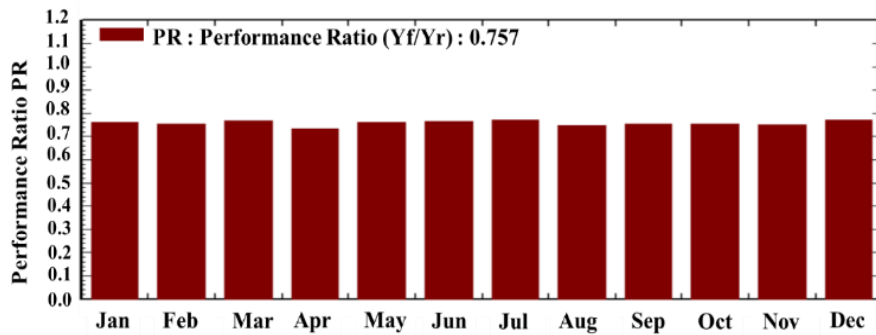


Fig. 9 - Performance Ratio

#### 4.2.8. Sustainable Solar Power Plant System in Realizing SDGs

A solar power plant system with a Performance Ratio (PR) of 75.7% in this study is considered sustainable, meeting the ideal PR criteria of between 70%-90% (Yau & Lim, 2016). This success supports the achievement of SDG 7 regarding clean and affordable energy. In addition, this system supports SDG 9 by being an innovation in the renewable energy sector and providing an example for society to adopt. The implementation of solar power plants also supports SDG 11 for sustainable cities and settlements, providing environmentally friendly energy.

#### 4.2.9. CO2 Gas Emissions

Daily energy requirements at the research location are 166.82 kWh, with a CO2 emission factor of 0.743 CO2/kWh. If using fossil energy generators, daily CO2 emissions are 124.33 Kg. During a month, it reaches 3729.92 Kg, and in a year it reaches 44759.14 Kg. With solar power plants, clean electrical energy is produced without CO2 emissions for 25 years, reducing emissions by 1,118 tons over that period. Thus, the solar power plant system is considered sustainable and supports reducing CO2 emissions (Yau & Lim, 2016). The graph of CO2 emissions from fossil fuels is presented in Figure 10.

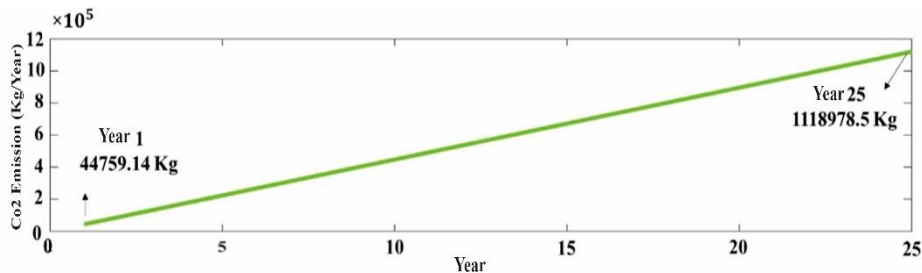


Fig. 10 - CO2 Gas Emissions

### 4.3. Economic Analysis

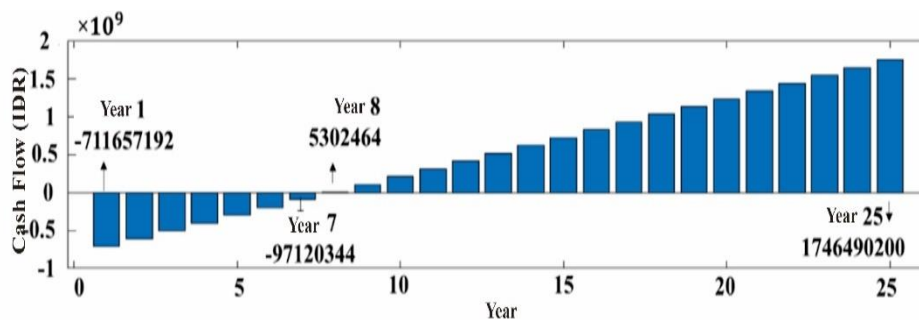
The service costs for the hybrid solar power plant in Beloh Hamlet are calculated at IDR 3.603.829. These costs refer to the minimum working wage of Mojokerto Regency with a working period of 12 times a year. By paying attention to the taxes on the purchase of each component, the initial investment cost calculation is obtained in accordance with Table 3 as follows:

**Table 3. Initial Investment Costs**

| No    | Component      | Amount | Unit price     | Unit price [+20% taxes] | Total           |
|-------|----------------|--------|----------------|-------------------------|-----------------|
| 1     | PV 250 Wp      | 184    | IDR 1.900.000  | IDR 2.280.000           | IDR 419.520.000 |
| 2     | Inverter 20 kW | 2      | IDR 30.000.000 | IDR 36.000.000          | IDR 72.000.000  |
| 3     | Battery 100 Ah | 224    | IDR 1.200.000  | IDR 1.440.000           | IDR 322.560.000 |
| Total |                |        |                |                         | IDR 814.080.000 |

In this study, the Operation and Maintenance (O&M) cost was calculated at 1% of the total initial investment, resulting in IDR 8.140.800 based on equation 9. Meanwhile, the additional cost for maintenance was calculated by equation 10, resulting in IDR 32.563.200. With a CRF value of 0.0936% (equation 11) and a cost of operation (COE) yield of IDR 1.001/kWh for 25 years (equation 12), the tariff of this solar power plant turns out to be slightly lower than the PT PLN tariff which is currently at IDR 1.500/kWh.

In Figure 11, it can be seen that in the first year, the cash flow was still negative until in the 7th year the cash flow was still negative, namely - IDR 97,120,344. Each year's income is constant, namely IDR 114.167.437 so that in the 7th year the incoming income still cannot cover the capital that has been invested. This is due to O&M costs of IDR 8.140.800 and service costs of IDR 3.603.829 each year. Furthermore, in the 8th year, the cash flow starts to look positive, namely IDR 5.302.460 the cash flow is positive until the 25th year with the nominal value of the net cash flow, namely IDR 1.746.490.200.



**Fig. 11 – cash flow**

#### 4.3.1. Net Present Value (NPV)

Based on Figure 12, the NPV is negative in the 1st year, namely -IDR 708.369.410. However, in the 2nd year, the NPV value is positive, namely IDR 97.880.176. The NPV is positive from the 2nd year to the 25th year, with a value of IDR 16.670.490. The 8% interest rate used refers to the BRI bank interest rate. Then, using equation 2.14, the total NPV is positive, namely IDR 404.631.838. This means the project is feasible to run because its NPV is > 0. The NPV calculation using the second experiment was carried out using an interest rate from another bank of 14%, resulting in a total negative NPV of IDR 27.415.487, so it can be seen that the appropriate interest rate applied in this study was

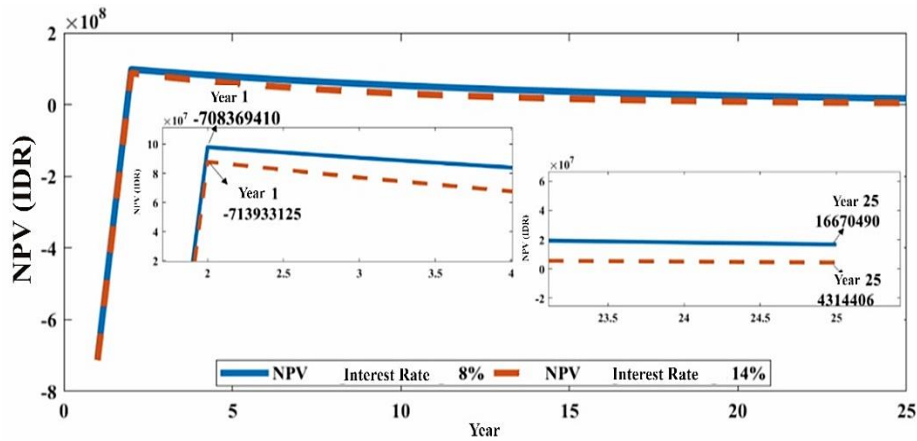


Fig. 12 - NPV

### 4.3.2. Payback Period (PP)

In Graph 13, it can be seen that the payback period for a 46 kWp solar power plant project with an initial investment cost of IDR 814.080.000 is in year 9 with a cumulative cash value of IDR 107.725.272.

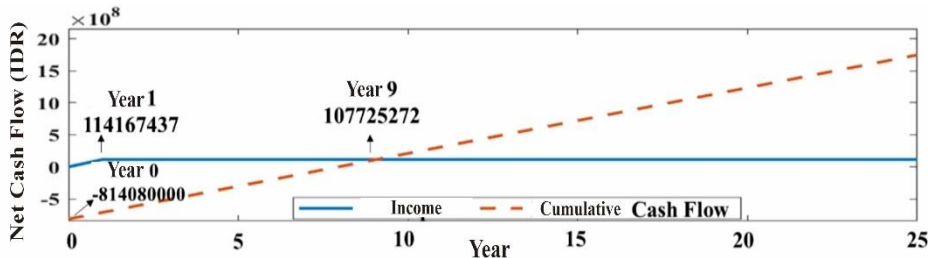


Fig. 13 - Payback Period

### 4.3.3 Break Event Point (BEP)

Based on calculations using equation 16, the results are shown in graphic image 14, which shows that the break-even point for the 46 kWp capacity solar power plant construction project occurred in year 8, with a nominal net cash flow of IDR 5.302.464.

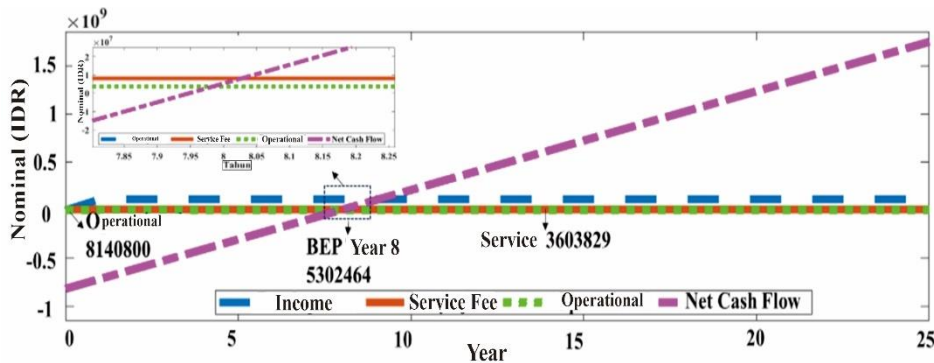


Fig. 14 - Break-Even Point

### 4.3.3. Return on Investment (ROI)

Based on calculations using equation 17, the results obtained are represented in graphic image 15, where it can be seen in the graph that the ROI value in the 1st year is still negative, namely -87% and the ROI is negative until the 8th year, this happens because the number The existing money is not sufficient to cover the investment costs that have been made, then only in the 9th year the ROI value is positive at 13%, meaning that in the 9th year you will only get a profit of 13%. In the following year, the ROI percentage increases until the 25th year, reaching 215%, indicating that this project will yield a profit on the investment, equal to 215% of the total investment.

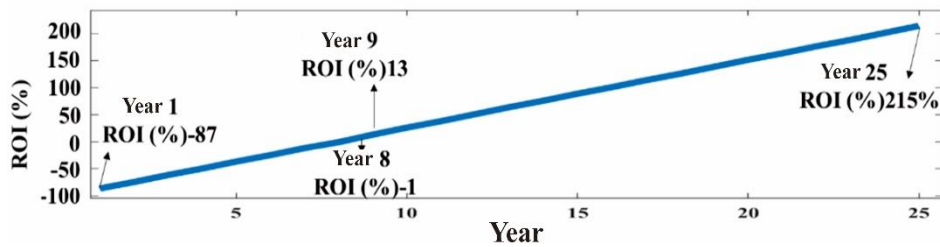


Fig. 15 - Return on Investment

## 5. Conclusion

Based on the research results, the solar power plant system in this study has a system performance of 75.7%. The economic feasibility analysis carried out indicates that this solar power plant system is feasible to operate. The sustainable solar power plant system in this research demonstrates the sustainability in converting solar energy into usable electrical energy. Apart from the clean and affordable energy target (SDG 7), the solar power plant system in this research also implements sustainable innovation (SDG 9) in the renewable energy sector and supports the target sustainable settlements (SDG 11) that are environmentally friendly. Suggestions for future research are to add variables such as shading, power quality, etc. It is hoped that in future research we can use the latest software and can carry out optimization to produce better solar power plant system output.

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