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Planning and Analysis of Integrated On-Grid Solar Power Plant using Pvsyst Software at the Krejengan Probolinggo Health Center

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A B S T R A C T

The demand for electrical energy in Indonesia continues to increase significantly. The government has set a target of 23% of the New and Renewable Energy (NRE) mix by 2025, one of which is through the installation of Solar Power Plants (PLTS). This study aims to design and analyze the technical and economic feasibility of On-Grid Solar Power Plant at the Krejengan Health Center, Probolinggo, using PVsyst software. The solar PV system is designed to have a capacity of 6600 watts to meet the daily electricity needs of the health center. The simulations carried out show that this solar power plant is able to produce enough energy with high efficiency. Economic analysis using the Net Present Value (NPV), Benefit-Cost Ratio (BCR), and Payback Period (PP) methods shows that this project is economically feasible. The implementation of this system provides significant economic benefits and contributes to the reduction of carbon emissions, in line with the national energy policy

1. Introduction

The demand for electrical energy in Indonesia is projected to increase up to nine times from 254.6 TWh in 2018 to 1,918 TWh in 2050[1]. The Government of Indonesia through Presidential Regulation No. 79 of 2014 has targeted the contribution of renewable energy in the energy mix to 23% by 2025[2]. To support the president's policy, the Minister of Energy and Mineral Resources made a policy on simplifying regulations from the installation of Solar Power Plants (PLTS) for the community through (PERMEN ESDM) Number 49 of 2018[3]. Solar Power Plants (PLTS) are one of the strategic options to support the achievement of this target.

This research was conducted at the Krejengan Health Center, Probolinggo, which in the 2025 Business and Budget Plan (RBA) will install On-Grid Solar Power Plant as a renewable energy source. The current electricity consumption installed in the health center is 5500 watts, and in 2025 it is projected to increase to 10,100 watts. The solar PV system is planned to supply energy to various facilities in the health center, such as emergency rooms, program rooms, sterilization rooms, and others.

This research aims to design an optimal On-Grid solar PV system, simulate system performance, and analyze economic feasibility as a long-term investment. PVsyst software is used in the simulation process to calculate the energy generated and analyze the potential energy savings.

To support this research, references are needed, including in the research of Adrian Mansur (2021) Analysis of the Performance of 50 Kwp On Grid Solar Power Plants Due to the Shadow Effect Using pvsyst Software From the results of the analysis, the production energy optimization data obtained by the software is as low as 0.45 MWh/year, from the real data of 70.51 MWh/year with the potential based on meteonorm data of 72.65 MWh/year to 73.1 Mwh/year based on meteonorm data of 7.3 in the software[4]

M.R. Wicaksana et al. (2019) in their research entitled Work Performance of 158 Kwp Rooftop Solar Power Plant at the Bali Governor's Office with the aim of reducing the supply of electrical energy from the PLN power grid. In the study, energy production through HelioScope simulation was obtained at 249,764 kWh per year with power losses of 9.1%[5]

According to Allan Ardiansyah et al. (2021) in designing the On Grid System rooftop solar power plant using PVsyst software at the office of the Probolinggo City Research and Development Regional Planning Agency, the results of the first scenario with a capacity of 21.6 kWp require an investment cost of IDR 267,000,000 and the second scenario with a capacity of 32.4 kWp with an investment cost of IDR 395,850,000. From the analysis of the two scenarios, in the first year, BAPPEDA LITBANG was able to save the cost budget of IDR43,979,592 and IDR64,642,977 so that the profit percentage reached 152% and 150% of the total investment budget, respectively[6]

In the research of Mohammad Jasa Afroni et al. (2022) entitled An Experimental Study of Partial Shading Effects on the PV Characteristic Curve, it was found that in the natural condition of solar panels experiencing partial shadowing, causing changes that occurred, there were complex PV characteristics with several MPPTs. The results of the experiment showed that the increase in partial shade resulted in the additional peaks growing gradually and the initial peaks gradually decreasing so that there was a shift to the other side of the curve. Using the Global Maximum Power Point Detection (GMPPD) method proposed here, the global peak can still be found regardless of its position in any part of the characteristic curve[7]

According to Nathawibawa et al. (2018) in their research entitled Analysis of Energy Production from Inverters on Grid-connected Solar Power Plants 1 MWp in Kayubihi Village, Bangli Regency, to find out the work of the inverter and the influence of the position of the string array can be obtained by mapping the percentage of energy production in each inverter. From the analysis obtained as a whole, the inverter gets optimal output energy, but in the southern part of the Kayubihi Solar Power Plant, more attention needs to be paid because it is covered with trees and shrubs[8]

According to Wirateruna E et al. (2022) in their research entitled Design of MPPT PV using Particle Swarm, a solar panel module simulation was carried out using MATLAB Simulink with an algorithm that can overcome the peak curve due to partial shade. As a result, the PSO algorithm can overcome partial shading with a quick response to maintain maximum results with a power optimization of 129 watts in about 0.4 seconds compared to a peturb with a time of about 0.06 seconds for a power optimization of 67 watts[9]

From the research of Badri F et al. (2021) with the title Design of Maximum Power Point Tracking Photovoltaic System Based on Incremental Conductance Algorithm using Arduino Uno and Boost Converter, a Maximum Power Point Tracking (MPPT) test has been carried out to track the maximum power of solar panels using a boost converter with the Incremental Conductance algorithm on the Arduino UNO. The test results show that the average value of power output with a resistive load of 36Ω is 7.34 W compared to 6.07 W without MPPT. The test results show that MPPT with Incremental Conductance algorithm can control PV output at the maximum power point[10]

In the study entitled Study on Increasing the Power of Solar Power Bankers from 50 Watts to 1000 Watts in Montallat I Village, North Barito Regency, Central Kalimantan by Moch. Fahrulrozi et al. (2019) concluded that increasing the power of solar PV from 50 Watts to 1000 Watts can be done by increasing the capacity of solar panels, batteries, and inverters. With this addition, solar PV can be used for a wider range of household needs, including electronic equipment[11]

2. Method

This study uses a quantitative approach with experimental methods and data analysis. The design of solar PV is carried out using PVsyst software, which is a special simulation software for solar power systems. The location of the research is at the Krejengan Health Center, Probolinggo, with data taken from field observations and climate data at the research site. The stages of the research can be seen in the following flow chart image.

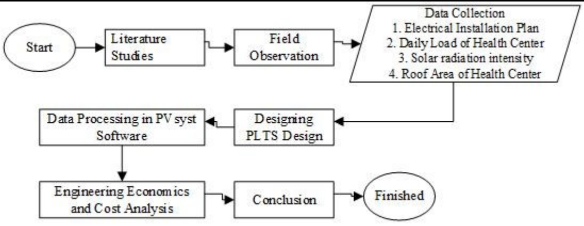

Figure 1. Research Flow Chart

In Figure 1 above, the research begins with a literature study from journals and previous research on the use of PVsyst software, solar power plant planning, and economic analysis of solar power plant investment. Furthermore, field observations were carried out at the Krejengan Health Center to collect data such as the layout of electrical installations, roof area, and solar radiation intensity. The data is used to design solar PV using PVsyst software, determine the number of panels, the type and brand of panels, and the inverter used. The simulation results are used to calculate the installation cost and economic analysis. The research ended with a conclusion to realize the solar power plant project at the Puskesmas.

The stages in using PVsyst Software in assisting in the analysis and design of solar PV are as follows:

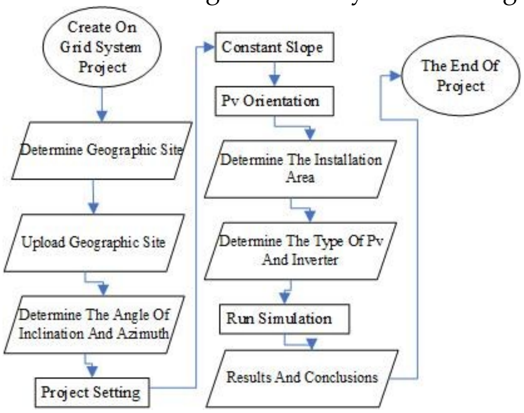

Figure 2. Flowchart Simulation on PVSYST

The design stage of on-grid solar power plants using PVSyst software begins by determining the geographical location of the Krejengan Health Center through coordinate points and annual solar irradiation data, using meteorological databases that are updated in real-time, such as MeteoNorm, NASA-SSE, PVGIS, and others. Next, the parameters of maximum cell temperature, minimum cell temperature, and operational conditions are determined. The tilt angle and direction of the solar panel are also optimized. After that, an area measurement was carried out to determine the specifications of solar panels and inverters, followed by simulations to get optimal design and system performance data. This process ends with the conclusion of the solar PV system planning

After the planning of the solar PV system is completed, it is carried out. The next stage is to analyze economic feasibility. Economic feasibility analysis is an economic analysis to ensure the sustainability of a project. If a project is able to provide better or similar benefits as needed at a lower cost, then the project is declared economically feasible. The principles in engineering economics are needed to help make decisions that will have a financial impact in the future

The NPV method is a method that states the projected future cash flow into the current value or discounted as the basis for comparison in the interest rate.

$PWC=\sum Cc\ (FBP)t$ (1)

$PWC=\sum Cb\ (FBP)t$ (2)

$NPV=PWB-PWC$ (3)

The BCR method is a comparison between the entire profit and the production cost of a project. BCR has the following general formula:

$$BCR = \frac{benefit}{cost}$$

DPP is an analysis to measure the period of return on an investment by considering the time value of money and the risk of income inflows for the return of invested capital. The length of the return period (k) can be known if the BEP conditions:

$$k_{(PP)} = \sum_{t=0}^{k} \quad CF_t \geq 0 \qquad (5)$$

3. Result and Discussion

In the 2025 RBA, the Krejengan Health Center will install 7800 VA of power with the need to expand, repair, build and add new building infrastructure with the R-1/TR tariff group category for old buildings with a cost per kWh of IDR 1,444.70 and R-3/TR for new buildings with a cost per kWh of IDR 1,699.53. The following is a table of the cost of the Krejengan Health Center for RBA in 2025 with new buildings that use the R-3/TR tariff group for the 2024 period.

Table 1. PLN Energy Usage Bill

Month	Energy Usage (kWh)	Payment
April	803	IDR 1,364,722
May	801	IDR 1,361,323
June	802,3	IDR 1,363,532
July	801,8	IDR 1,362,683
August	801,4	IDR 1,362,003
Total	**4009,5**	**IDR 6,814,265**

From the table, it can be seen that the electricity consumption of the R-3 / TR 6600 VA tariff group will only be installed in March 2024 so that the load data displayed starts from April to August 2024.

After knowing the monthly load of the Krejengan Health Center, the next step is to determine the electrical layout of the priority buildings that will be installed with solar PV. Prioritize the layout of electricity that will be installed by solar power plants

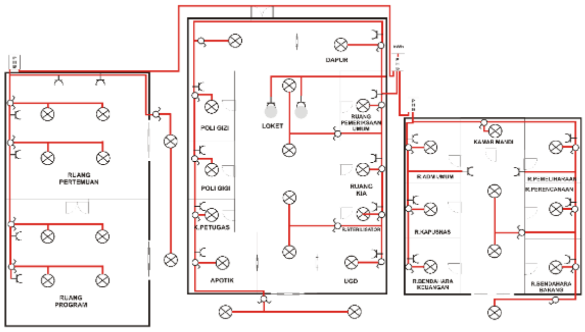

Figure 3. Layout of Electrical Installation of Priority Building

In figure 3 above, it can be seen that there are 3 main buildings that are the main rooms for services at the Krejengan Health Center. The 3 buildings use R-3 / TR 6600 VA type electricity with the center of the KWh meter located in the central building which is equipped with an electrical distribution panel to distribute power to the entire building

In the planning process of Solar Power Plants, it is necessary to run simulations on pvsyst software. The climate data is in the form of Temperature, Wind Speed, Humidity Percentage and Horizontal Global Radiation (GHI) which can be accessed through the Data Access Viewer [6]. The following is Nasa climate data with the location of the Krejengan Health Center in 2023.

Table 2. NASA Climate Data

Month	Global Hori-zontal Irradia-tion (kWh/m2/hari)	Horizontal Dif-fuse Irradiation (kWh/m2/hari)	Temp (^{o}C)
Jan	5,44	2,79	27,6
Feb	5,21	3,20	27,4
Mar	5,22	3,00	27,8
Apr	5,60	2,53	28,0
Mei	5,12	2,36	28,4
Jun	5,07	2,02	27,5
Jul	5,40	1,99	27,3
Ags	5,87	2,23	27,4
Sep	6,23	2,45	27,7
Okt	6,25	2,85	29,0
Nov	5,68	2,82	28,6
Des	5,41	2,96	28,1
Avr	5,54	2,60	27,9

Table 2 above explains Nasa's climate data with the location of the Krejengan Pusk-esmas. The average GHI value in 2023 is 5.54 kWh/m2 per day with an average temperature value of 27.9 oC. In addition, the average HDI value is 2.60 Wh/m2 per day with an average wind speed of 1.8 m/s.

Based on the observation results, the installation of solar panels is on the roof of buildings 3 and 6 with a flat roof. To get maximum power, it is necessary to pay attention to the level of slope when installing solar panels. To find out the direction and angle, the slope can be analyzed accurately using PVsyst software. The results of the PVsyst software show that the tilt of the solar panel is 14o facing west.

The design of solar power plants on the roof of the Krejengan Health Center uses solar panels from Trina Solar with a capacity of 500 Wp as many as 48 modules. Trina Solar was chosen because it is known for its efficient and durable solar panels. In determining the inverter, Huawei Technologies was chosen because it has a type of inverter with a high level of efficiency. In the design process, the solar power plant has been adjusted to the peak load of electrical energy needs at the Krejengan Health Center, which is 24 kW. The following is the wiring of the Krejengan Health Center

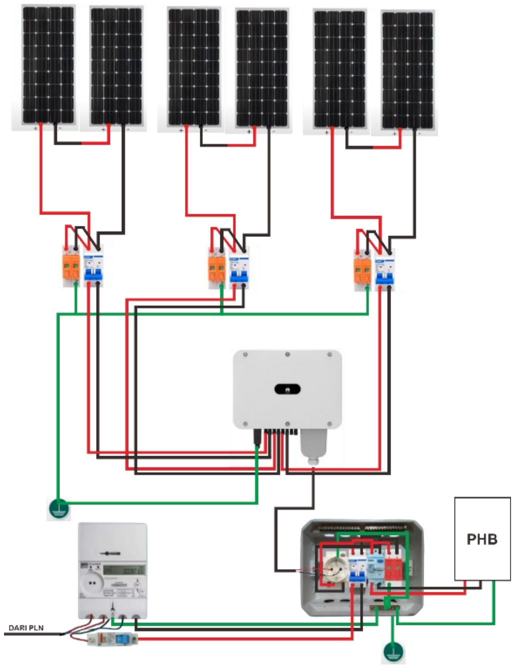

Figure 4. Wiring of PLTS Krejengan Health Center

Determining several basic subjects such as climate data, the angle of inclination of solar panels, calculating the upper area of the health center, determining the type of solar panels and inverters, now it has entered the simulation stage. The following are the simulation results from the PVSyst software:

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_User MWh	E_Solar MWh	E_Grid MWh	EFrGrid MWh
January	139.2	72.23	25.74	128.8	125.2	2.832	0.597	0.275	2.497	0.322
February	126.8	66.64	25.75	121.5	118.5	2.688	0.539	0.246	2.386	0.293
March	146.0	71.30	25.83	146.1	142.9	3.216	0.597	0.274	2.877	0.323
April	142.2	61.20	25.96	150.2	147.2	3.296	0.578	0.262	2.967	0.316
May	148.5	53.63	25.84	165.3	162.1	3.633	0.596	0.271	3.289	0.325
June	138.0	48.00	25.41	157.2	154.2	3.475	0.578	0.264	3.143	0.314
July	148.2	50.53	25.00	167.4	164.3	3.710	0.597	0.272	3.366	0.325
August	162.1	55.80	25.21	175.9	172.8	3.875	0.596	0.272	3.528	0.324
September	172.2	60.30	25.72	176.6	173.2	3.849	0.577	0.266	3.507	0.312
October	176.4	69.13	26.17	171.5	167.8	3.741	0.596	0.278	3.387	0.318
November	152.4	69.30	26.00	141.6	137.8	3.097	0.577	0.273	2.759	0.304
December	145.7	71.61	25.71	133.0	129.1	2.934	0.597	0.276	2.596	0.321
Year	1797.7	749.67	25.69	1835.1	1795.0	40.345	7.024	3.228	36.302	3.796

Figure 5. Main Result of Simulation

Overall based on figure 5, this solar system shows stable and excellent performance throughout the year. Most of the energy produced can be used for local needs or distributed to the power grid. With an annual energy production of 40,345 MWh and efficient distribution to the grid, the system demonstrates high efficiency and optimal performance.

The initial investment cost for the Krejengan Health Center solar power plant project consists of direct components such as the purchase of photovoltaic modules (solar panels) and in-inverters, as well as indirect components such as logistics costs (shipping) and installation costs. The installation cost covers the entire installation work, including the installation of the module support structure (panel rack). The following is a table of calculation of the investment cost of installing solar power plants at the Krejengan Health Center

Table 3. Calculation of Initial Investment Cost of Solar PV System

Name	Number of Units	Total Price (IDR)
Trina Solar Vertex 500W+ TSM-DE18M(II)	51	63.750.00
Inverter SUN2000-30KTLM3 480V	1	26.053.761
Mounting bracket per meter	51	4.440.000
PV SLOCABLE 2x6 mm per meter	270	7.020.000
NYY 4x16 mm SUPREME per meter	12	1.260.000
Kwh Exim (Expor Impor)	1	2.062.000
Fuse Holder DC 20 A 2p TOMZN	3	516.000
MCB DC 20 A 2p Suntree	3	504.000
SPD DC 1000 V 40 kA 3p Suntree	3	690.000
MC4 Socket Connector	109	545.000
Din Rail Stop Electric Socket	1	31.500
MCB AC 2p Suntree	1	64.000
SPD AC 2p Suntree	1	160.000
ELCB 2P Hager	1	252.000
PGI Grounding Rod	1	245.000
Development and Installation	1	5.000.000
Total Budget		112.593.261

The budget in the table in table 3 above will be submitted by the head of planning of the Krejengan Health Center which will be approved by the head of the Krejengan Health Center to Waluyojati Hospital as the main hospital of the Krejengan Health Center. After that, the proposal will be submitted to CSR PT Waskita Karya (Persero) Tbk as the financier in the realization of the construction of solar power plants at the Krejengan Health Center.

After knowing the simulation results on the PVsyst software, the following is a table of the results of the calculation of monthly electrical energy savings after the installation of solar power plants.

Table 4. Calculation of Savings in Electrical Energy Use

Month	Initial Billing	Post-Solar Bill
January	IDR 1.363.023	IDR 547.248,66
February	IDR 1.363.023	IDR 497.962,29
March	IDR 1.363.023	IDR 548.948,19
April	IDR 1,364,722	IDR 537,051,48
May	IDR 1,361,323	IDR 552.347,25
June	IDR 1,363,532	IDR 553.652,42
July	IDR 1,362,683	IDR 552.347,25
August	IDR 1,362,003	IDR 550.647,72
September	IDR 1.363.023	IDR 530.253,36
October	IDR 1.361.323	IDR 540.450,54
November	IDR 1.363.023	IDR 516.657,72
December	IDR 1.363.023	IDR 545.549,13
Total	IDR 16.353.727,43	IDR 6.453.115,41
Average	IDR 1.362.810,62	IDR 537.759,63

In addition to the savings in annual electricity bills, in Table 4. 6 There is an excess power generated by the power generation system, which is with an average of 2,825 kWh/month. The following is a table of results from the advantages of excess power in the power generation system exported to PLN

Table 5. Advantages of Excess Power Export of Electricity

Month	E_Grid (MWh)	Advantages of Electricity Export
January	2.497	IDR 2.758.422
February	2.386	IDR 2.635.801
March	2.877	IDR 3.178.206
April	2.967	IDR 3.277.629
May	3.289	IDR. 3.633.340
June	3.143	IDR 3.472.055
July	3.366	IDR 3.718.402
August	3.528	IDR 3.897.362
September	3.507	IDR 3.874.164
October	3.387	IDR 3.741.600
November	2.759	IDR 3.047.852
December	2.596	IDR 2.867.787
Total	36.302	IDR 40.102.620

Before entering the calculation of economic feasibility, basic calculation data is needed as a reference in economic feasibility analysis. The following is a list of basic data calculations in economic analysis.

Table 6. Basic Data for Economic Feasibility Analysis Calculation

No	*Assumptions*	Value
1	Diskonto (i)	6,25%
2	*Initial Investment*	IDR 112.593.261
3	*Revenue Prediction* (15 *years*)	IDR 350.00.000
4	*Inflation*	2,6%
5	*Project Lifetime*	15 *years*
6	OPEX	IDR 3.377.797

From the data of table 6 above, the calculation of economic feasibility analysis can be carried out. The following is a table of PVNCF calculations to determine the economic feasibility analysis

Table 7. PVNCF Calculation Results

Year	Net Cash (IDR)	Cash Out (IDR)	Discount	PWB (IDR)	PWC (IDR)
1	49.003.167	3.377.797	0,94	46.120.627	3.179.103
2	48.778.152	3.466.338	0,89	43.208.328	3.070.528
3	48.553.138	3.557.199	0,83	40.479.066	2.965.660
4	48.328.123	3.650.442	0,78	37.921.383	2.864.374
5	48.103.108	3.746.130	0,74	35.524.539	2.766.547
6	47.878.094	3.844.325	0,70	33.278.460	2.672.061
7	47.653.079	3.945.094	0,65	31.173.703	2.580.803
8	47.428.065	4.048.505	0,62	29.201.415	2.492.661
9	47.203.050	4.154.627	0,58	27.353.293	2.407.529
10	46.978.036	4.263.530	0,55	25.621.554	2.325.305
11	46.753.021	4.375.288	0,51	23.998.901	2.245.889
12	46.528.007	4.489.975	0,48	22.478.492	2.169.185
13	46.302.992	4.607.668	0,45	21.053.914	2.095.101
14	46.077.978	4.728.447	0,43	19.719.153	2.023.547
15	45.852.963	4.852.391	0,40	18.468.572	1.954.437
TOTAL	711.420.979	61.107.763	9,6	455.601.407	37.812.736

In the calculation of NPV or Net Present Value, the total PWB with a value of IDR 455,601,407.67 is calculated by the total PWC with a value of IDR 37,812,736. for the calculation of NPV is as follows

NPV = total PWB – total PWC

NPV = IDR 455,601,407.67- IDR 37,812,736.74

NPV = IDR 417,788,630.93 > 0

Based on the results of the calculation, the NPV value is positive or more than zero, then the project is declared feasible because the calculation of the project investment achieves profits for a certain period.

After the NPV is declared feasible, the next step is to determine the BCR value or Benefit Cost Ratio. The BCR calculation uses an interest rate of 6.25% per year 2024. The following is the calculation of the BCR value

BCR = PWB/PWC

= (IDR 455,601,407.67)/(IDR 37,812,736.74)

= 12,049 > 1

In the calculation results of the BCR above, a value of 12.049 is obtained greater than 1, then the investment is declared feasible.

The results of NPV and BCR show that the investment in planning the installation of rooftop solar power plants at the Krejengan Health Center is feasible, so then the calculation of DPP or Discounted Payback Period needs to be done to measure the payback period on an investment by considering the time value of money and the risk of income inflows for the return of investment capital. The following is the calculation of the DPP

DPP = n+$\frac{a-b}{c-b}$ x 1

DPP = 2+ (IDR 29,513,936,14)- IDR 37,513,405.90.

DPP = 1.21 = 1 year 2 months

The result of the calculation of the DPP or Discounted Payback Period, the time needed for the investment capital to return is 1 year and 2 months

4. Conclusion

In the research entitled "Planning and analysis of integrated on-grid solar power plants using pvsyst software at the Krejengan Probolinggo Health Center" has the following conclusions:

Conducting field observations and determining load predictions in accordance with the Budget Plan (RBA) is the basic data needed in designing solar power plants with optimal capacity using PVsyst software. After that, determining the slope of the solar module, determining the type of inverter, determining the type of solar panel and determining the single line diagram is the last stage in designing solar PV. Based on the results of planning and simulation using PVsyst software, the optimal design of the Solar Power Plant (PLTS) for the Krejengan Health Center is a solar power plant system with a total capacity of 24 kW consisting of 48 solar panel modules, each with a capacity of 500 Wp

The main determinant in the assessment of economic feasibility analysis is to evaluate the results of the calculation of electricity export profits, NPV (Net Pre-sent Value), BCR (Benefit Cost Ratio) and DPP (Discounted Payback Pe-riod) by taking into account the inflation rate, discounts, operation and maintenance of solar power plants adjusted to the life of the project as a long-term investment scale.

From the economic analysis carried out, the Krejengan Health Center managed to save electricity costs by 60.54%. Before the installation, the total annual electricity cost reached Rp 16,353,727.43, and after the installation, the cost was reduced to Rp 6,453,115.41. With these significant savings in electricity costs, the solar system provides tangible economic benefits, while supporting renewable energy programs that are environmentally friendly and good for long-term investment.

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