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Utilizing PVSyst for planning a hybrid system rooftop solar power plant at Makassar Eye Hospital

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Abstract
Installing rooftop Solar Power Plants (SPP) represents the most efficient solution for reducing substantial electricity consumption in office buildings and hospitals, as Makassar Eye Hospital exemplifies. The research commences by addressing concerns about electricity availability and daily usage at the hospital while evaluating the solar radiation potential. Subsequently, the development of the SPP system begins. A location assessment is conducted using various tools to gather the necessary data for SPP design. In this study, the planning phase involves the utilization of PVSyst software for the technical analysis of electrical energy generation and system performance calculations. Additionally, the economic analysis includes evaluating the initial investment costs for establishing the SPP and considering prevailing market prices for components. The feasibility of the SPP investment is determined by calculating key financial metrics, including the Payback Period (PP), Net Present Value (NPV), Internal Rate of Return (IRR), Profitability Index (PI), and Return on Investment (ROI). According to the economic analysis findings, the initial investment cost for the SPP amounts to Rp. 544,031,733. The energy production value per kilowatt-hour (kWh) stands at Rp. 1,278, resulting in a Payback Period (PP) of 13.8 years, a Net Present Value (NPV) of Rp. 138,182,638, an Internal Rate of Return (IRR) of 11.51%, and a Return on Investment (ROI) of 25.4%. These results affirm the plan's feasibility, as the IRR value surpasses the Discount Rate (8.43%).

Keywords:
Feasibility;
Makassar Eye Hospital;
Planning;
PVSyst;
Rooftop Solar Power Plant;

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INTRODUCTION

Indonesia, the world's largest archipelagic nation consisting of approximately 17,500 islands [1][2], harbors a population of around 220 million people, with 60% residing in rural areas [3]. Despite this, a substantial proportion of the country's power plants still heavily rely on fossil fuels [4][5]. According to the 2018-2027 State Electricity Company (PLN) Electricity Supply Business Plan (RUPTL), over 82% of Indonesia's electricity is generated from fossil fuels, leaving a modest 18% derived from renewable sources. The strategic construction of Solar Power Plants (SPP) emerges as an effective solution to electrify isolated rural regions, leveraging Indonesia's abundant renewable energy resources, particularly solar power [6, 7, 8]. Data indicates that Indonesia has an impressive solar energy potential of 207,898 MW, yet its current utilization is a mere 0.04% [9][10]. The country's tropical climate and archipelagic nature result in a substantial solar energy potential characterized by an average daily radiation (insolation) of 4.5 kWh/m²/day [11]. This potential offers an economically viable and year-round source of renewable energy [12]. Consequently, the adoption of SPP technology emerges as the ideal approach to harness this abundant solar energy resource.

PVSyst, a computer software dedicated to studying, sizing, and analyzing complete PV systems [13], plays a pivotal role in the technical design and economic feasibility assessment of centralized off-grid solar PV installations, such as the one planned for the Makassar Eye Hospital. The simulation results obtained from PVSyst offer crucial performance data for each requisite component, determine the SPP capacity, and ascertain the number of components needed. The economic analysis extends to reviewing the necessary investment based on prevailing component prices [14]. Numerous studies have successfully utilized PVSyst for comprehensive SPP planning and analysis. For instance, a proposal for an efficient, sustainable, and environmentally friendly SPP system connected to the electricity grid was formulated for Islamia University Bahawalpur, Pakistan [15]. In Afghanistan, a 700KWp grid-connected SPP in Daikundi province underwent simulation and performance evaluation using PVSyst software [16]. Another study developed a standard procedure for designing large-scale grid-connected solar PV systems (5 MW) and simulated the performance of a 5 MW grid-connected solar PV system over its lifetime using PVSyst software [17]. Additionally, a detailed demonstration involved modeling and simulating a 1 MW photovoltaic power plant in a northern Moroccan zone using PVsyst software for performance evaluation [18]. Furthermore, a discussion centered around a PV system at the Electrical Engineering Laboratory at Jenderal Achmad Yani University, connected to the electricity network and producing 220VAC/50Hz characteristics, with analysis performed using PVSyst [19].

PVSyst has emerged as a highly efficient tool in the strategic planning of SPP, as evidenced by numerous research studies. In our investigation for formulating an SPP plan at Makassar Eye Hospital, PVSyst stands out as the preferred tool. Urban areas often face challenges in securing extensive land parcels for SPP construction, making rooftops the most viable option [20]. Leveraging rooftops for SPP installations proves to be the most effective strategy in reducing electricity consumption in office buildings and hospitals [21][22], with Makassar Eye Hospital serving as a prime example of a building well-suited for this approach.

Currently, Makassar Eye Hospital supplies 197 KVA of low-voltage electricity from PLN, yet its infrastructure can accommodate up to 500 KVA. Additionally, the hospital is equipped with a 500 KVA Generator Set, serving as a backup power source for emergencies. Given its status as a healthcare institution, the hospital places a premium on a reliable electricity supply, crucial for both medical and non-medical equipment. The proposed implementation of an SPP reduces electricity expenses and aligns with government initiatives to advance Renewable Energy [23][24]. This study advocates for planning an electrical system and economic analysis computations to establish an SPP at Makassar Eye Hospital, utilizing PVSyst as the primary tool.

MATERIAL AND METHODS

This study employs an experimental methodology, predominantly utilizing quantitative techniques to design the SPP on the rooftop of Makassar Eye Hospital. It involves calculations, measurements, and the development of SPP circuitry and components tailored for the hospital. The research initiative begins with a survey of electricity availability and daily consumption at Makassar Eye Hospital, coupled with an evaluation of the solar radiation potential. Subsequently, the SPP system is designed, and a site assessment is conducted using diverse references and tools to collect essential data.

SPP System Design

In devising the SPP for Makassar Eye Hospital, the research team customized the design to align with the building's specifications and the existing power infrastructure. This process included determining the system's capacity, selecting appropriate components, performing size calculations, and generating a layout image of the installation.

Technical Analysis

After finalizing the design of the SPP system, a technical analysis is conducted, relying on simulation outcomes derived from PVSyst. This analysis assesses both the electrical energy generated and the system's overall performance.

Economic Analysis

This analysis considers the initial capital expenses associated with installing an SPP system, using current market prices for components. Additionally, it calculates the capital return costs based on the viability of the SPP investment, assessed through metrics such as the Payback Period (PP), Net Present Value (NPV), Internal Rate of Return (IRR), Profitability Index (PI), and Return on Investment (ROI) [25].

Payback Periode (PP)

The PP is the timeframe required for the project's generated revenue to recoup the initial investment, as expressed in (1) [25].

$$PP = Year\ Before\ recovery + \frac{Investment\ Cost}{NPV\ Cumulative} - II \quad (1)$$

With:

Year before recovery : The number of years before the final purchase year
Investment Cost : Initial investment costs
Cumulative NPV : Net cash amount.
II : Initial Investment

The criteria for decision-making on whether to accept or reject an investment proposal are as follows:

a. An investment is considered feasible if the payback period is shorter than the expected life of the project.
b. Conversely, an investment is regarded as unfeasible if the payback period exceeds the anticipated project lifespan.

Net Present Value (NPV)

The NPV represents the current value of all net cash flows, determined by applying a discount factor. The formula for NPV is illustrated in (2) [25].

$$NPV = \sum_{t=1} \frac{NCFt}{(1+i)^t} - IA \quad (2)$$

Here are the criteria for determining the eligibility of an investment based on its Net Present Value (NPV):

a. An investment is considered feasible if the NPV is positive (greater than 0).
b. Conversely, an investment is deemed unworthy if the NPV is negative (less than 0).

Internal Rate of Return (IRR)

The IRR is the interest rate that equates the present value of an investment to the anticipated net gains over the life of the project. In a scenario with two known NPV values, the IRR can be calculated using the equation depicted in (3) [25].

$$IRR = i1 \frac{NPV1}{NPV2 - NPV1}(i2 - i1) \quad (3)$$

With:

NPV1 must be above 0 (NPV1 > 0)
NPV2 must be below 0 (NPV2 < 0)

Profitability Index (PI)

The formula for calculating the PI is expressed as shown in (4) [25, 26, 27].

$$PI = \frac{Present\ Value\ of\ future\ cashflow}{Initial\ Cost} \quad (4)$$

The decision-making criteria for accepting or rejecting an investment proposal based on the PI are as follows:

a. An investment is considered feasible if the PI is greater than one (> 1).
b. Conversely, an investment is deemed unsuitable if the PI is less than one (< 1).

Return of Investment (ROI)

ROI represents the return on an investment, typically expressed as a percentage, indicating the expected rate of return from the investment. A project is deemed feasible if the ROI value is positive. The calculation for ROI is defined by the equation shown in (5) [25, 26, 27].

$$ROI = \frac{Net\ Benefita\ at\ the\ end\ of\ life\ time}{Total\ Investment} x100\% \quad (5)$$

RESULTS AND DISCUSSION

The simulation results for designing a Hybrid System on the roof of the Makassar Hospital Building using PVSyst 7.3 are presented in Figure 1 below.

According to Figure 1, the SPP on the roof of the Makassar Eye Hospital Building generates 56.218 kWh/year before inverter conversion. After the conversion process and accounting for losses, the electrical energy produced decreases to 54.691 kWh/year. The breakdown of this production results in 54.682 kWh/year available for the load and 9 kWh/year that cannot be used. This information is also visualized in the Loss Diagram in PVSyst 7.3, as depicted in Figure 2.

Main Results

System Production

Produced Energy	54682 kWh/year	Specific Production	1657 kWh/kWp/year
Used Energy	217993 kWh/year	Performance Ratio PR	82.26 %
		Solar Fraction SF	25.08 %

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_User kWh	E_Solar kWh	EUnused kWh	EfrGrid kWh
January	163.0	73.42	26.57	155.4	150.7	4340	18514	4220	0.073	14294
February	127.6	75.97	26.81	125.5	121.7	3522	16723	3417	1.885	13306
March	148.7	84.55	26.96	148.3	144.0	4151	18514	4029	1.986	14485
April	162.0	71.29	26.99	166.0	162.1	4636	17917	4508	1.123	13410
May	159.2	72.78	27.57	167.0	163.0	4681	18514	4555	0.323	13959
June	149.0	62.77	26.70	158.1	154.3	4456	17917	4336	0.000	13581
July	174.1	57.99	26.72	184.3	180.1	5160	18514	5026	0.000	13489
August	196.4	59.15	27.02	203.8	199.5	5664	17917	5516	0.000	12998
September	188.6	64.23	27.24	191.9	187.6	5308	18514	5162	3.303	12755
October	201.6	76.48	27.90	198.6	193.8	5491	18514	5347	0.000	13167
November	172.8	79.46	27.04	166.8	161.9	4652	17917	4526	0.000	13391
December	156.2	76.58	27.02	148.6	143.8	4157	18514	4038	0.000	14476
Year	1999.3	854.66	27.05	2014.3	1962.6	56218	217993	54682	8.693	163311

Figure 1. Energy Production from SPP on the Roof of the Makassar Eye Hospital Building

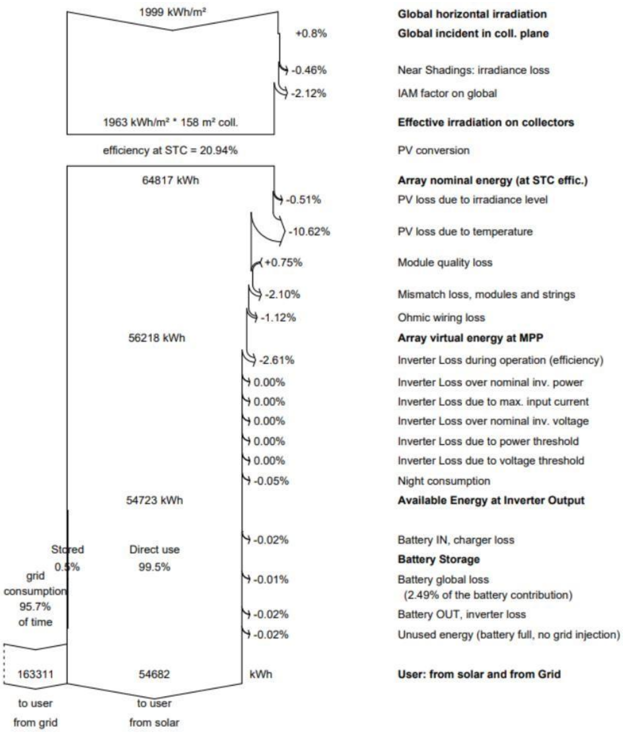


Figure 2. Loss Diagram of Hybrid SPP Makassar Eye Hospital PVSyst 7.3

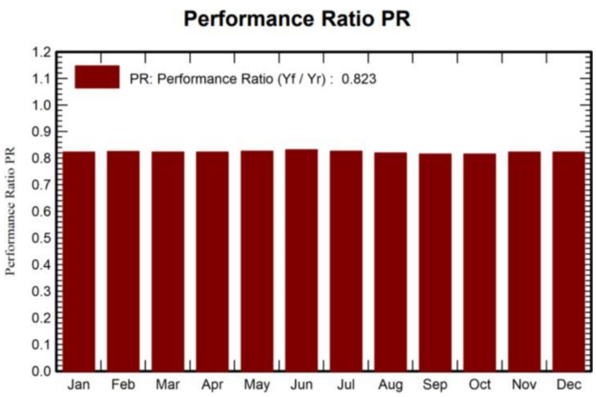


Figure 3. Graph of Hybrid SPP Performance Ratio for Makassar Eye Hospital

Regarding Figure 3, the Performance Ratio of the Makassar Mata Hospital Roof SPP system is 0.823, equivalent to 82.3%.

Economic Analysis

After simulating the SPP design in the PVSyst 7.3 application, an economic analysis was carried out to assess the viability of the project. This section outlines the results of the economic calculations for the simulated SPP system.

General information

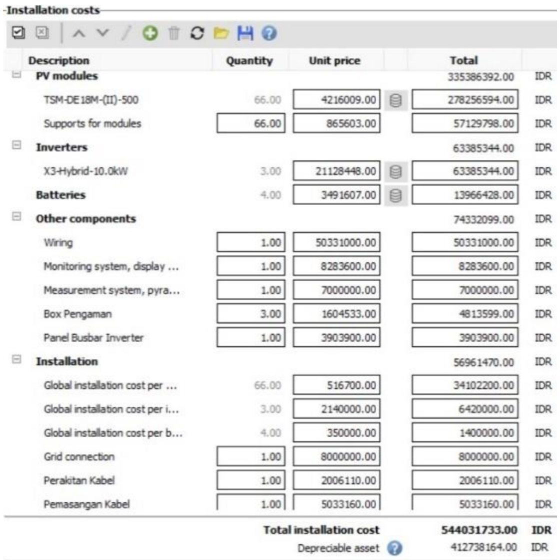
The Rooftop SPP Design Project at Makassar Eye Hospital has a projected lifespan of 25 years and is designed for implementation in 2023. This design requires essential data, including inflation, interest, and PLN electricity buying and selling tariffs. Data obtained from the Central Statistics Agency reveals that the Rupiah Credit Interest Rate in the National Private Bank Group, specifically for Investment, was 8.43% in April 2023. Additionally, information compiled from Bank Indonesia (BI) indicates that the inflation rate in Indonesia for June 2023 was 3.52%.

According to Presidential Decree Number 112 of 2022, the purchase price for electricity from SPP in Sulawesi Island is Rp.1.893 per kWh for the first ten years and Rp.1.032 per kWh for subsequent years. In contrast, the electricity purchase price from PLN for tariff classification for purely social activities, such as eye hospitals, is Rp.1.114,74 per kWh. This can be summarized as follows:

1) Inflation Data = 3.52 %/year
2) Discount Rate = 8.43 %/year
3) Electricity Purchase Price =Rp.1.522,88 /kWh
4) Electricity Sales:
   a. First 10 Years = Rp. 1.893 per kWh
   b. Next 15 Years = Rp. 1.032 per kWh
   c. Average for 25 Years = (Rp. 1.893 × 10 + Rp. 1.032 × 15) /25 = Rp. 1.376,77 per kWh

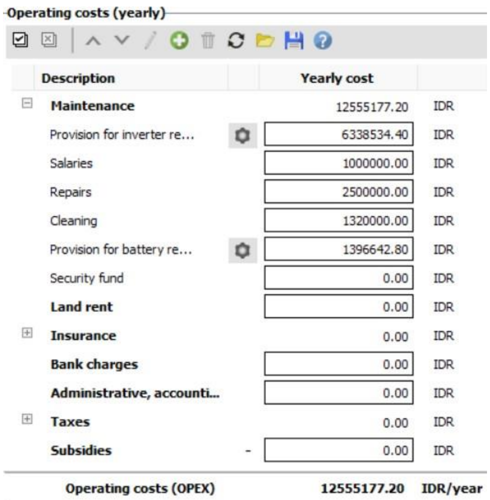
Hybrid System

Based on the Hybrid SPP Cost Budget Plan for Makassar Eye Hospital, the data can be entered into the PVSyst 7.3 application as follows. Figure 4 shows that the cost to build the Hybrid SPP at Makassar Eye Hospital is Rp. 544.031.733. Figure 5 reveals that the annual cost for the operation and maintenance of the Hybrid SPP at Makassar Eye Hospital is Rp. 12.555.177. Based on Figure 6 and Figure 7, it is shown that the PVSyst design results have an Initial Investment value of Rp. 544.031.733, with an energy production value per kWh of Rp. 1.278, a payback period of 13,8 years, an NPV value of Rp. 138.182.638, an IRR value of 11.51%, and an ROI of 25.4%. Therefore, proceeding is feasible because the IRR value is greater than the Discount Rate (8.43%).


Installation costs

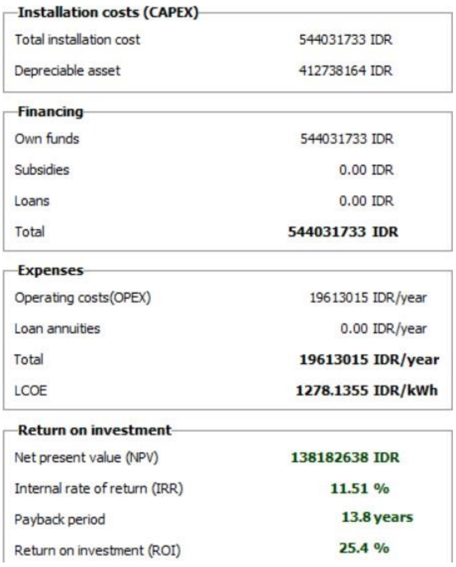
Description	Quantity	Unit price	Total	
PV modules			335386392.00	IDR
TSM-DE18M-(II)-500	66.00	4216009.00	278256594.00	IDR
Supports for modules	66.00	865603.00	57129798.00	IDR
Inverters			63385344.00	IDR
X3-Hybrid-10.0kW	3.00	21128448.00	63385344.00	IDR
Batteries	4.00	3491607.00	13966428.00	IDR
Other components			74332099.00	IDR
Wiring	1.00	50331000.00	50331000.00	IDR
Monitoring system, display ...	1.00	8283600.00	8283600.00	IDR
Measurement system, pyra...	1.00	7000000.00	7000000.00	IDR
Box Pengaman	3.00	1604533.00	4813599.00	IDR
Panel Busbar Inverter	1.00	3903900.00	3903900.00	IDR
Installation			56961470.00	IDR
Global installation cost per ...	66.00	516700.00	34102200.00	IDR
Global installation cost per i...	3.00	2140000.00	6420000.00	IDR
Global installation cost per b...	4.00	350000.00	1400000.00	IDR
Grid connection	1.00	8000000.00	8000000.00	IDR
Perakitan Kabel	1.00	2006110.00	2006110.00	IDR
Pemasangan Kabel	1.00	5033160.00	5033160.00	IDR
		Total installation cost	544031733.00	IDR
		Depreciable asset	412738164.00	IDR

Figure 4. Installation Cost of Hybrid SPP at Makassar Eye Hospital


Operating costs (yearly)

Description	Yearly cost	
Maintenance	12555177.20	IDR
Provision for inverter re...	6338534.40	IDR
Salaries	1000000.00	IDR
Repairs	2500000.00	IDR
Cleaning	1320000.00	IDR
Provision for battery re...	1396642.80	IDR
Security fund	0.00	IDR
Land rent	0.00	IDR
Insurance	0.00	IDR
Bank charges	0.00	IDR
Administrative, accounti...	0.00	IDR
Taxes	0.00	IDR
Subsidies	- 0.00	IDR
Operating costs (OPEX)	12555177.20	IDR/year

Figure 5. Operating Costs of SPP Hybrid Makassar Eye Hospital



Installation costs (CAPEX)	
Total installation cost	544031733 IDR
Depreciable asset	412738164 IDR
Financing	
Own funds	544031733 IDR
Subsidies	0.00 IDR
Loans	0.00 IDR
Total	544031733 IDR
Expenses	
Operating costs(OPEX)	19613015 IDR/year
Loan annuities	0.00 IDR/year
Total	19613015 IDR/year
LCOE	1278.1355 IDR/kWh
Return on investment	
Net present value (NPV)	138182638 IDR
Internal rate of return (IRR)	11.51 %
Payback period	13.8 years
Return on investment (ROI)	25.4 %

Figure 6. Hybrid SPP Investment Feasibility Value

Technical Analysis

Based on the analysis that has been carried out, the final results are obtained in the form of general parameters such as the number of solar panels, inverters, and batteries, as well as the value of System Power and the energy production of each generator, total production from the system, and system performance. These results are shown in Table 1. Table 1 shows that the Produced Energy is 54.70 MWh/year, with a system performance of 82.30%.

Table 1. Technical Analysis Results

Item	Parameter
Project Lifetime (year)	25
Solar Panel (unit)	66
System Power (kWp)	33
Inverter (unit)	3
Battery (unit)	4
Electricity Load (kWh)	597.00
Produce Energy (MWh/year)	54.70
System Performance (%)	82.30

Economic Analysis

Based on the economic analysis carried out, the final results are obtained in the form of Hybrid SPP Construction Investment Costs and O&M Costs, shown in Table 2.

Table 2. O&M, Replacement & Operation Costs

Item	Cost (Rp)
O&M Cost (per year)	4,820,000
Replacement Cost (per year)	7,735,177
Operation Cost (per year)	12,555,177

Detailed economic results (IDR)

Year	Electricity Sale	Own Funds	Run Costs	Deprec. Allow.	Taxable Income	Taxes	After-Tax Profit	Self-cons saving	Cumul. Profit	& Amorti.
0	0	544031733	0	0	0	0	0	0	544031733	0.0%
1	0	0	12555177	16509527	0	0	-12555177	83313960	-478774153	12.0%
2	0	0	12997119	16509527	0	0	-12997110	83313960	-416956004	23.0%
3	0	0	13454518	16509527	0	0	-13454618	83313960	-364105664	33.1%
4	0	0	13929221	16509527	0	0	-13928221	83313960	-313970165	42.3%
5	0	0	14418494	16509527	0	0	-14419454	83313960	-268003488	50.7%
6	0	0	14928025	16509527	0	0	-14825025	83313960	-225922803	58.5%
7	0	0	15451421	16509527	0	0	-15451421	83313960	-187411882	65.5%
8	0	0	15956311	16509527	0	0	-15953311	83313960	-152179065	72.0%
9	0	0	16553348	16509527	0	0	-16556345	83313960	-119958113	76.0%
10	0	0	17141200	16509527	0	0	-17141200	83313960	-90501674	83.4%
11	0	0	17744570	16509527	0	0	-17744570	83313960	-83582786	89.3%
12	0	0	18389179	16509527	0	0	-16309179	83313960	-38993220	92.8%
13	0	0	19015174	16509527	0	0	-16015774	83313960	-16641107	97.0%
14	0	0	19635129	16509527	0	0	-19685129	83313960	3949730	100.7%
15	0	0	20378060	16509527	0	0	-20378045	83313960	22641778	104.2%
16	0	0	21098383	16509527	0	0	-21095383	83313960	39034108	107.3%
17	0	0	21837909	16509527	0	0	-21831909	83313960	38213880	110.1%
18	0	0	22808804	16509527	0	0	-22606604	83313960	68357191	112.7%
19	0	0	23432328	16509527	0	0	-23402356	83313960	12229933	115.1%
20	0	0	24228119	16509527	0	0	-24225119	83313960	93939846	117.3%
21	0	0	23078879	16509527	0	0	-25076579	83313960	104561206	118.2%
22	0	0	25562855	16509527	0	0	-25861665	83313960	114247302	121.0%
23	0	0	28875506	16509527	0	0	-28875505	83313960	122000041	122.6%
24	0	0	27821323	16509527	0	0	-27821523	83313960	130975470	124.1%
25	0	0	28830841	16509527	0	0	--29500841	83313960	138182638	125.4%
Total	0	344041733	490025375	412738164	0	0	-490325375	2082849005	138182638	123.4%

Figure 7. Detailed Economic Results of Hybrid SPP

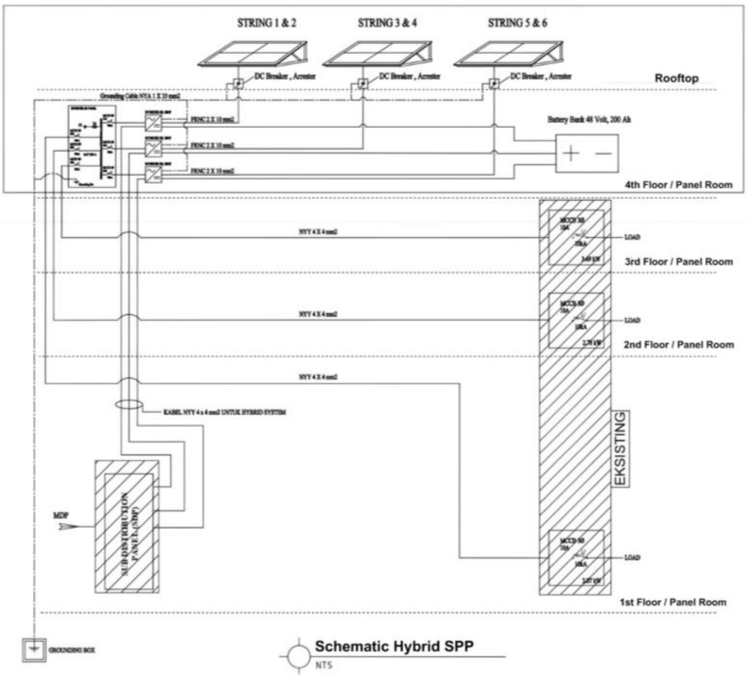


Figure 8. Schematic Hybrid SPP

Based on Table 2, the investment costs that must be incurred for the construction are Rp. 546,526,305, and the operation cost is Rp. 12,555,177 per year.

Feasibility Analysis

Based on the economic analysis that has been carried out, the final results are obtained in the form of Initial Investment Cost, Energy Cost per kWh, NPV, IRR, and ROI, which are shown in Table 3.

Based on Table 3, the Initial Investment value is Rp. 544,031,733, with an energy production value per kWh of Rp. 1,278, a payback period of 13.8 years, an NPV value of Rp. 138,182,638, an IRR value of 11.51%, and an ROI of 25.4%. Therefore, the proceeding is feasible because the IRR value is greater than the Discount Rate (8.43%).

Table 3. Feasibility Analysis Results

Item	Value
Initial Investment Costs (Rp)	544,031,733
Energy Cost per kWh (Rp)	1,278
Payback Period (Year)	13.8
Net Present Value (Rp)	138,182,638
IRR (%)	11.51
Return on Investment (%)	25.40

System Design Recommendations

The Hybrid SPP system utilizes six sets of solar panel arrays, with each array consisting of 11 series. Each panel set array has a capacity of 5.5 kWp, and every two array sets are connected to 1 inverter unit with a capacity of 10 kW. Additionally, the system employs four batteries arranged in series to form a system voltage of 48 Volts, serving as storage for the produced energy. The PLN network is connected to the distribution panel at the research location. The wiring diagram for this SPP system can be observed in Figure 8.

Main Component Specifications

The main components in designing a Hybrid Solar Power Plant are solar panels, inverters, and batteries. The selection of components is tailored to the electrical energy load profile and land availability at the location (roof of the Makassar Eye Hospital), as well as component specifications and costs that will be used as the initial investment. Table 4 below illustrates the main component specifications of the Hybrid SPP system.

Table 4. Main Component Specifications

Component	Specification
Solar Panel Type Monocrystalline Trinasolar	500 Wp
Inverter Solaxpower X3 Hybrid	10.0 kW
Narada Battery 12NDT200	12V, 200Ah

CONCLUSION

The design of the Hybrid SPP system for the Makassar Eye Hospital Building, utilizing PVSyst software, includes 66 units of Trina Solar solar panels with a nominal power of 500 Wp, three units of Solax Power Hybrid Inverters, each equipped with 2 SCCs, and 4 Narada brand 12V batteries with a 4-series configuration, each rated at 200Ah.

The system demonstrates a production capacity of 54.682 kWh/year with a performance of 82.3%. The initial SPP investment cost is Rp. 544,031,733, and the energy production value is Rp. 1,278 per kWh. This yields a payback period of 13.8 years, an NPV of Rp. 138,182,638, an IRR of 11.51%, and an ROI of 25.4%. Notably, the project is deemed feasible as the IRR exceeds the discount rate of 8.43%.

Based on the Carbon Balance calculation in the PVSyst 7.3 software, it is determined that the value of carbon emissions that can be reduced if this project runs for its intended lifespan of 25 years is 832.322 tons. PVsyst software is a more appropriate choice for planning the rooftop Solar Power Plant at the Makassar Eye Hospital. The main reasons for this recommendation include model accuracy, level of detail, flexibility, and the far superior performance comparison of PVsyst Software.

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