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Analysis of Solar Power Generation System Requirements Based on Economic Factors in Photovoltaic Specification Selection

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Abstract

A solar power generation system is a significant investment, and its economic viability is crucial. Analyzing economic factors helps ensure that the selected photovoltaic specifications are cost-efficient, the financial investment is justified, and the energy needs, the project remains sustainable in the long term. It assists stakeholders in making decisions based on economic considerations, energy production and environmental impact. This research aims to analyze the requirements for solar power generation and the selection of photovoltaics based on economic factors. The results of this research explain photovoltaic specifications in terms of efficiency, capacity, technology, and characteristics to understand how they affect the requirements of solar power generation systems. Based on economic factors such as initial investment costs, operational costs, and long-term economic benefits generated. The simulation of the photovoltaic system indicated that photovoltaics with a capacity of 485Wp, using monocrystalline type Canadian Solar HiKu5 Mono PERC, produce the highest output value of 8 kWp using 15 solar panels. It indicates that these specifications offer a high potential for electricity production. The highest economic value amounts to IDR 71,874,000 with an annual yield of 2,920 kWp. The use of monocrystalline photovoltaics is superior and more durable compared to polycrystalline. However, monocrystalline types tend to be more expensive in terms of price. Nevertheless, investment in types can provide long-term benefits in terms of efficiency, durability, and higher electricity production potential despite the higher initial costs. The selection of photovoltaic types should consider these factors, including available budget, desired efficiency, and overall system requirements.

Keywords: budget, capacity, durability, efficiency, monocrystalline photovoltaics

INTRODUCTION

Tropical regions like Southeast Asia are suitable for effectively developing solar power plants because of the abundant solar energy throughout the year. Solar power plants are electricity generation systems that rely on solar radiation as their primary energy source. These systems convert solar radiation into electricity through solar panels made up of solar cells. The amount of radiation the solar panels receive

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dramatically affects the system's efficiency. Typically, the solar panels' solar radiation is measured in kilowatt-hours per square meter per day (kWh/m^2-day). The higher the radiation received by the solar panels, the greater the electricity generated by the solar power plants. Weather conditions, such as clear and cloudless, highly influence solar power plants. High levels of sunshine result in high radiation and produce a significant amount of electrical energy. However, during adverse weather conditions like cloudy and rainy days, the amount of radiation received by the solar panels decreases, reducing the amount of electrical energy generated.

Increasing temperature in photovoltaic cells will decrease energy conversion efficiency and reduce power output (Dubey et al., 2013; Santiago et al., 2018). Different temperature coefficients are required for each type of solar cell (Ponce-Alcantara et al., 2014). These coefficients indicate the percentage change in power output per unit change in temperature. The higher the temperature coefficient, the more significant the impact of temperature changes on the solar cell's power output (Cotfas et al., 2018). Therefore, to improve the efficiency of photovoltaic solar systems, it is vital to control the temperature of the solar cells effectively. Over time, the performance of a solar power system can decline. One of the leading causes of this performance degradation is PV module degradation, which mechanical damage, weather influences, and ageing can cause. Insufficient maintenance and upkeep can also contribute to performance degradation.

Using renewable energy by industrial companies can help reduce electricity costs and greenhouse gas emissions (Shukla et al., 2017). Renewable energy sources such as solar power, wind, hydro, and bioenergy have significant potential to reduce dependence on fossil energy sources and enhance energy security. As stated by the International Renewable Energy Agency (IRENA), the transition to renewable energy is crucial for sustainable development. It can improve the quality of life and the economy of communities (Mengi-Dinçer et al., 2021). In recent years, there has been a constant increase in installed renewable energy capacity and electricity generation. From 2011 to 2020, the total global installed capacity for all types of renewable energy increased by 2.1 times. Solar energy capacity increased tenfold, while wind power capacity tripled. However, the installed solar energy capacity decreased from 2.4% to 0.9%. The electricity generated from solar energy increased significantly from 2011 to 2020 (Fais et al., 2014). From 2011 to 2018, the electricity generated from solar energy increased 8.5 times more than wind power, which only increased 2.9 times. Then, from 2018 to 2019, photovoltaic plant installations increased by 12%. All of this indicates that solar energy is a rapidly growing renewable energy source, significantly contributing to the increase in capacity and the amount of electricity generated from renewable energy.

On-grid solar photovoltaic systems are connected to the existing electricity grid. The loads directly consume the electricity the photovoltaic system generates, eliminating the need for large-scale energy storage. This system is suitable for areas with a stable and adequate electrical grid. In Indonesia, the regulations support feed-in tariffs for residential users, which allow photovoltaic system owners to sell the electricity they produce to utility companies (Hasudungan & Sabaruddin, 2018). However, for commercial and industrial users, the current regulations in Indonesia support feed-in tariffs. Therefore, commercial and industrial photovoltaic system users must install components with zero export function. If the load is lower than the photovoltaic system's production, the inverter will automatically limit the power output to match or be less than the load. In general, commercial and industrial-scale photovoltaic systems are expected to optimize the benefits of electricity production, offering the advantage of purchasing electricity at a lower price compared to the selling price from the utility company. However, it is essential to consider the necessary regulations and permits to ensure that the use of photovoltaic systems complies with applicable rules and regulations.

The cost of electricity from solar photovoltaic systems has significantly decreased in recent years. According to the latest report from IRENA, the cost of electricity from photovoltaic systems dropped by 85% between 2010 and 2020 (Jäger-waldau, 2020). Solar electricity is the cheapest source of electricity in many countries worldwide. A comprehensive analysis of photovoltaic projects worldwide indicates that the costs of photovoltaic power generation will continue to decline, enhancing their competitive advantage over other energy sources. Strengthen the business case for solar photovoltaic and reinforce the role of solar energy in driving global energy transformation. Factors such as improved production efficiency, lower module costs, and reduced installation expenses contribute to the decreasing cost of solar electricity. With lower costs, photovoltaic systems become more attractive to investors and allow for larger-scale deployment, thereby increasing the penetration of solar energy in the global energy system.

Solar power systems involve substantial upfront costs, including solar panels, inverters, installation, and related equipment. An economic analysis helps assess the overall cost of the system and determines whether it is a financially sound investment. Solar systems have ongoing operational and maintenance expenses, such as cleaning, repairs, and monitoring. Analyzing these costs helps project owners estimate the long-term financial commitment required to keep the system running efficiently. Economic analysis identifies potential financial risks associated with solar power projects, such as changes in electricity prices, system performance, or maintenance costs. Understanding these risks helps in devising risk mitigation strategies. Previous research discusses the economic analysis of planning a grid-connected solar power system connected to the electrical network using HOMER and photovoltaic system simulations. From an economic perspective, it analyzed the investment costs and cash flow during the solar power systems investment. The technical economic analysis calculations showed that the energy selling price at IDR 840.2 per kWh was not feasible, as it could not offset the high initial investment costs. After conducting sensitivity analysis by increasing the selling price of energy, the results of the technical economic analysis based on HOMER simulations can be feasible if the selling price of energy is IDR 1932.8/kWh. At the same time, it is IDR 1440.2/kWh for a photovoltaic system, as it can cover the investment costs (Hidayat et al., 2019). Previous research was conducted on the economic feasibility analysis of solar power systems in Indonesia. This research discusses the technical and economic value issues related to solar power systems. Some studies argue that the Net Present Value of solar power systems indicates feasibility for construction. In contrast, other studies suggest that the lifetime of solar power systems averages over 20 years, with a payback period of up to 10 years. Thus, the cumulative cash flow exceeds the initial investment value within the 20-year lifespan of solar power systems, so investing in solar power systems is feasible for implementation (Suripto & Fathoni, 2021).

Photovoltaic systems require a high initial investment due to the hardware involved in harnessing and converting solar energy into electricity, including solar panels, inverters, and power conditioning equipment. Therefore, it is essential to perform economic calculations considering the initial investment required, ongoing operational and maintenance costs, and the payback period. Feasibility studies are also necessary to determine whether the development of a photovoltaic system is practical in a specific location. They evaluate factors such as land availability, solar resource quality at the site, and grid connectivity. An analysis of the location conditions and expected electricity consumption is necessary to determine the system size and the amount of hardware required for a photovoltaic installation. These calculations should also consider the number of installations, the type of solar panels used, and the type of inverters employed.

METHOD

Research Planning

In analyzing requirements, various data types are needed as supporting elements for conducting this research. Data are obtained from various research sources, which are used for theoretical support. Field studies are conducted to obtain data directly, and guidance consultations are conducted with professors and experts related to the research topic. This research utilizes a quantitative method, presenting the results in numerical form. The approach in this study involves combining data, understanding the data, and presenting the results, all of which are part of the quantitative research method. In the processing of this research, a clear framework is needed at its level. This framework consists of stages that will be used to address the issues in this study. The research procedure generally includes six stages, shown in Fig. 1.

Research Tool Using Photovoltaic System

A photovoltaic system is a software tool used in solar photovoltaic systems to simulate, design, measure, and analyze data related to photovoltaic systems. The photovoltaic system software is a highly comprehensive program, and we cannot address all the issues that arise from using Pvsyst (Salmi et al., 2022; González-Peña et al., 2021)

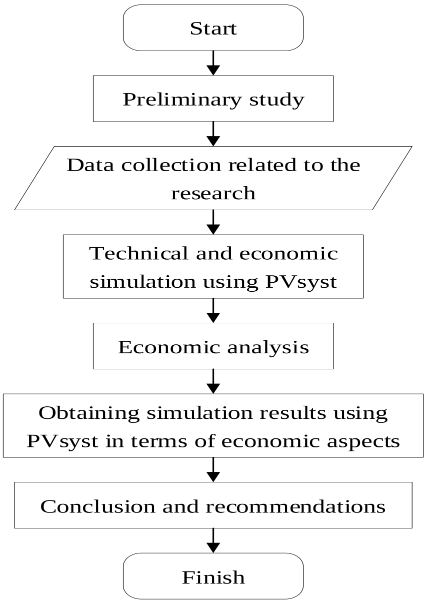

Figure 1. Research Planning of Using Photovoltaic System

Assuming that software is installed on the computer, users can start by double-clicking on the photovoltaic system icon. Once an application is open, four menu sections will appear on the computer screen: preliminary design, project design, pumping, and databases (Kumar et al., 2021; Gurupira & Rix, 2017). Users use these four sections to operate. The four screen sections can be explained as follows. The first step in this simulation is to input solar radiation data for the area to be analyzed, such as South Tangerang City, the total power output of the system, and the solar panels and inverters used. Then, the simulation calculations can be run.

Research Materials

This research requires various materials/ components, including two different types of solar panels, two different brands/types, and two different capacities. Monocrystalline solar panels utilize silicon as the primary material for constructing the solar cells. This silicon material is thinly sliced using specialized technology, ensuring that the resulting solar cell pieces are identical and perform well. These solar panels use single-crystal solar cells with an efficiency of 20.6%. This research analyses two monocrystalline solar panel brands and types: Canadian Solar HiKu5 Mono PERC with type CS3Y - 485MS and GCL - P6/96 Polycrystalline. Polycrystalline solar panels are made of silicon as well. However, manufacturers combine several pieces of silicon to form panel slices instead of single-crystal silicon. Polycrystalline solar modules are also called "polycrystalline" or polycrystalline silicon. Electrons cannot move freely due to multiple crystals in each cell. It is why polycrystalline solar modules are slightly less efficient than monocrystalline ones. In this research, two different brands and types of polycrystalline solar panels are analyzed: Sun-Earth DXM5-36P 100W - Monocrystalline and EastechSolar ESF-100PC – Polycrystalline, as shown in Table 1.

Table 1. Photovoltaic Specifications

Specifications	Canadian Solar Photovoltaic	GCL P6/96 Photovoltaic	Sun-Earth Photovoltaic	Eastech Solar Photovoltaic
ELECTRICAL DATA STC				
Nominal Max. Power (Pmax)	485 W	450 W	100 W	100 W
Opt. Operating Voltage (Vmp)	44.4 V	50.9 V	18.5 V	18.3 V
Opt. Operating Current (Imp)	10.94 A	8.84 A	5.41 A	5.47 A
Open Circuit Voltage (Voc)	53.1 V	61.4 V	22.7 V	22.6 V
Short Circuit Current (Isc)	11.62 A	9.33 A	5.75 A	5.78 A
Module Efficiency	20.60%	17.4 %	15.2 %	15.9 %
Operating Temperature	-40°C ~ +85°C	-40°C ~ +85°C	85% Rh, -40°C ~ +85°C	-
Max. System Voltage	1000V (IEC/UL)	1500V (IEC/UL)	1000VDC	600V
Max. Series Fuse Rating	20 A	15 A	10 A	-
Power Tolerance	0 ~ + 10 W	0 ~ + 5 W	-	-
ELECTRICAL DATA NMOT*				
Nominal Max. Power (Pmax)	362 W	325.66 W	73.85 W	-
Opt. Operating Voltage (Vmp)	41.5 V	46.9 V	17.20 V	-
Opt. Operating Current (Imp)	8.74 A	6.95 A	4.35 A	-
Open Circuit Voltage (Voc)	50.1 V	57.2 V	21.13 V	-
Short Circuit Current (Isc)	9.38 A	7.36 A	4.66 A	-
MECHANICAL DATA				
Cell Type	Monocrystalline	Polycrystalline	Monocrystalline	Polycrystalline
Cell Arrangement	156 [2 x (13 x 6)]	96 (6 x 16)	36 (125 x 125)	36 (156 x 98)
Dimensions	2252 x 1048 x 35 mm (88.7 x 41.3 x 1.38 in)	2568 x 1008 x 40 mm (101.10 x 39.69 x 1.57 inches)	1195 x 550 x 35 mm	940 x 670 x 30 mm
Weight	25.7 kg (56.7 lbs)	36.5 kg	7.8 ± 3% kg	6.45 kg
TEMPERATURE CHARACTERISTICS				
Temperature Coefficient (Pmax)	-0.34 % / °C	-0.41 % / °C	-0.4 % / °C	-0.05 % / °C
Temperature Coefficient (Voc)	-0.26 % / °C	-0.32 % / °C	-0.3 % / °C	-0.05 % / °C
Temperature Coefficient (Isc)	0.05 % / °C	0.055 % / °C	+0.05 % / °C	+0.01 % / °C
Nominal Module Operating Temperature	42 ± 3°C	45 ± 2°C	45 ± 2°C	

The comparison between solar panels will depend on several key factors such as efficiency, price, warranty, manufacturer's reputation, and technical specifications. Panel efficiency measures its ability to convert sunlight into electrical energy, with higher efficiency resulting in more energy production. Prices vary by brand and type, so compare prices for equivalent panels. A more extended warranty indicates the manufacturer's confidence in product quality and assures good performance. Additionally, consider the manufacturer's reputation; leading manufacturers typically produce high-quality products.

RESULT AND DISCUSSION

This study utilizes four types of photovoltaic panels with a capacity of 485 W, including both monocrystalline and polycrystalline panels. Additionally, two types of PV panels with a capacity of 100 W are included, consisting of monocrystalline and polycrystalline panels. The specific PV panel types analyzed in this study are the Canadian Solar HiKu5 for 485 W monocrystalline panels and the GCL - P6/96 for 485W polycrystalline panels. Both types of PV panels are paired with the SG40CX inverter. For the 100 W capacity, the monocrystalline panel used is the Sun-Earth DXM5-36P, paired with the SOFAR 3K-7.5KTL-G2 inverter. The polycrystalline panel used is the Eastech Solar ESF-100PC, paired with the SOLARMAX 1000-3000SP inverter.

Comparison of Photovoltaic Module Types

This analysis found that the Canadian Solar brand has a maximum solar panel output power of 7.76 kWp. In comparison, the Sun Power brand produces a maximum output power of 7.46 kWp. The maximum output voltage of Canadian Solar panels is 637 V. In contrast, Sun Power panels generate a maximum voltage of 617 V. Canadian Solar brand has a maximum output current of 11 A, while Sun Power brand produces a maximum current of 12. Additionally, there is a difference in the total output between the two brands, with the Canadian Solar brand having a total output of 8 kWp.

In contrast, the Sun Power brand has a total output of 8.19 kWp. Canadian Solar brand utilizes 16 PV modules, while Sun Power uses 18. The total module area for the Canadian Solar brand is 35.3 m², while for the Sun Power brand, it is 38.8 m². The analysis results are presented in Table 2.

The analysis observed that the CGL P6-96 brand has a maximum solar panel output power of 6.60 kWp, while the VSG 505 brand produces a maximum output power of 6.34 kWp. The maximum output voltage of the CGL P6-96 panels is 551 volts, whereas the VSG 505 panels generate a maximum voltage of 435 volts. The CGL P6-96 brand has a maximum output current of 11 amperes. At the same time, the VSG 505 brand produces a maximum current of 15 A. There is also a difference in the total output between the two brands, with the CGL P6-96 brand having a total output of 7 kWp, while the VSG 505 brand has a total output of 7.07 kWp. The CGL P6-96 brand utilizes 15 PV modules, while the VSG 505 brand uses 14 modules. The total module area for the CGL P6-96 brand is 33.1 m², while for the VSG 505 brand, it is 53.2 m², as the analysis results are presented in Table 3.

Comparison of Economic Value of Photovoltaic Modules

The economic simulation planning of this PV system is conducted using Pvsyst software with different types of PV. Based on the economic simulation of Monocrystalline PV type with 485W capacity, Canadian Solar brand, and an initial investment of IDR 71,874,000, it can generate 2,920 kWp per year with an annual maintenance cost of IDR 7,187,400. Meanwhile, for the Monocrystalline PV type with 485W capacity, Sun Power 485W brand, and an initial investment of

IDR 69,524,000, it can generate 2,989 kWp per year with an annual maintenance cost of IDR 6,952,000. Based on the simulation data using Pvsyst software, the comparing of economic values for the Monocrystalline type with 485W capacity yields different output results and specifications.

The economic comparison of Polycrystalline PV type with 485W capacity, specifically GCL - P6/96 485Wp brand, shows that the simulation with an initial investment of IDR 67,210,000 can generate 2,555 kWp per year with an annual maintenance cost of IDR 6,721,000. On the other hand, the VSG 505 Ertex Solar 485W brand, with an initial investment of IDR 64,750,000, can generate 2,314 kWp per year with an annual maintenance cost of IDR 6,475,000. Based on the simulation data using Pvsyst software, the comparison of economic values for the Polycrystalline type with 485 W capacity yields different output results and specifications, which are shown in Table 4.

Table 2. Comparison of Simulation Results for Photovoltaic Types with a Capacity of 485WP

Data Sheet Spesifikasi	Monocrystalline		Polycrystalline	
	Canadian Solar 485W	Sun Power	GCL P6-96	VSG 505 Ertex Solar
Maximum Solar Panel Output Power (P mpp)	7.76 kWp	7.46 kWp	6.60 kWp	6.34 kWp
Maximum Solar Panel Output Voltage (U mpp)	637 V	617 V	551 V	435V
Maximum Solar Panel Output Current (I mpp)	11 A	12 A	11 A	15 A
Total Output (STC)	8 kWp	8.19 kWp	7 kWp	7.07 kWp
Total PV Modules	16 Modules	18 Modules	15 Modules	14 Modules
Total Module Area	35.3 m^2	38.9 m^2	33.1 m^2	53.2 m^2

Table 3. Comparison of Simulation Results for Photovoltaic Types with a Capacity of 100WP

Data Sheet Spesifikasi	Monocrystalline		Polycrystalline	
	Sun-Earth DXM5-36	Luxor LX-100M	Eastech Solar ESF-100PC	Canadian Solar 100W
Maximum Solar Panel Output Power (P mpp)	7.60 kWp	7.12 kWp	1.6 kWp	2.1 kWp
Maximum Solar Panel Output Voltage (U mpp)	630 V	633 V	255 V	358 V
Maximum Solar Panel Output Current (I mpp)	11 A	11 A	5.5 A	6.0 A
Total Output (STC)	8 kWp	8 kWp	2 kWp	2.4 kWp
Total PV Modules	76 Modules	40 Modules	16 Modules	24 Modules
Total Module Area	50.0 m^2	51.8 m^2	10.1 m^2	23.7 m^2

Table 4. Comparison of Economic Values based on PV Type with 485WP Capacity

Data Sheet Specifications	Monocrystalline				Polycrystalline			
	Qty	Canadian Solar 485W (IDR)	Qty	Sun Power (IDR)	Qty	GCL P6/96 (IDR)	Qty	VSG 505 Ertex Solar (IDR)
PV module	16	50,624,000	15	49,024,000	15	45,960,000	16	44,250,000
Inverter	1	21,250,000	1	21,250,000	1	21,250,000	1	20,500,000
Maintenance Cost		7,187,400		6,952,000		6,721,000		6,475,000
Total		71,874,000		69,524,000		67,210,000		64,750,000

Based on the Pvsyst software simulation data, comparing economic values for the Monocrystalline type with 100W capacity shows different output results and specifications. In the case of the Sun-Earth DXM5-36P brand, the economic simulation with an initial investment of IDR 82,000,000 can generate 1,460 kWp per year with an annual maintenance cost of IDR 8,200,000. On the other hand, the Luxor LX brand, with an initial investment of IDR 84,000,000, can generate 2,598 kWp per year with an annual maintenance cost of IDR 8,400,000. For the Polycrystalline PV type with a 100W capacity, the Eastech Solar ESF-100PC brand, with an initial investment of IDR 16,800,000, can generate 730 kWp per year. It has an annual maintenance cost of IDR 1,688,000.

Meanwhile, the Canadian Solar 100W brand, with an initial investment of IDR 15,600,000, can generate 766 kWp per year. It has an annual maintenance cost of IDR 1,560,000. These comparisons can be observed in Table 5.

Determining The Required Number of Pv Panels

We can calculate the required number of panels by understanding the power generated by each PV panel. It applies to both Monocrystalline and Polycrystalline PV types with power outputs of 485 Wp and 100 Wp, respectively. These calculations clearly show how many panels must be installed to meet the desired power requirements. The results of these calculations can be found in Table 6, which presents comprehensive and detailed data on the number of panels needed for each PV type.

Calculation of Solar Panel Series-Parallel Configuration

The calculations in Table 7 aim to determine the overall power output of the solar panels when arranged in a series-parallel configuration for 485 W and Table 8 for 100 W (Tabanjat et al., 2015). This configuration allows for increasing the current by connecting the panels in parallel while increasing the voltage can be achieved by connecting them in series (Calcabrini et al., 2021), (Archila et al., 2021). By understanding the relationship between series and parallel connections, it becomes possible to optimize the solar panel system's performance based on specific power requirements and voltage limitations.

Table 5. Comparison of Economic Values based on PV Type with 100WP Capacity

Data Sheet Specifications	Monocrystalline				Polycrystalline			
	Qty	Sun-Earth DXM5-36 (IDR)	Qty	Luxor LX-100M (IDR)	Qty	Eastech Solar ESF-100PC (IDR)	Qty	Canadian Solar 100W (IDR)
PV module	76	76,000,000	80	72,000,000	15	15,680,000	16	14,400,000
Inverter	1	6,000,000	1	12,000,000	1	1,200,000	1	1,200,000
Maintenance Cost		8,200,000		8,400,000		1,688,000		1,560,000
Total		82,000,000		84,000,000		16,800,000		15,600,000

Table 6. Determining the Required Number of PV Panels

Capacity	Types	Number of panels (P_{wp} / P_{mpp})	Rounded Results (panels)
485 W	Monocrystalline	88.992 W / 485 Wp = 183.48 p	183
	Polycrystalline	75.169 W / 485 Wp = 154.98 p	155
100 W	Monocrystalline	65.664 W / 100 Wp = 65.664 p	66
	Polycrystalline	68.688 W / 100 Wp = 68.988 p	69

Table 7. Calculation of Series-Parallel Configuration for 485 W Solar Panels

Specification	Monocrystalline		Polycrystalline	
	Canadian Solar 485W	Sun Power	GCL - P6/96	VSG 505 Ertex Solar
Open Circuit Voltage (Voc) (V)	53.10	54.00	61.40	86.39
Maximum Power Voltage (Vmp) (V)	44.40	44.80	50.90	69.20
Maximum Power Current (Imp) (A)	10.95	10.83	8.84	7.33
The following data is extracted from the inverter specifications:				
Minimum Sistem Voltage (Vmin) (V)	200	200	200	425
Maximum Sistem Voltage (Vmax) (V)	1100	1100	1100	1100
Serial-Parallel Configuration of Solar Panels				
Minimum series configuration (Vmin/Vmp) (panels)	4.5 ≈ 5	4.4 ≈ 4	3.9 ≈ 4	6.1 ≈ 6
Maximum series configuration (Vmax/Voc) (panels)	20.7 ≈ 21	20.37 ≈ 20	17.9 ≈ 18	12.7 ≈ 13
Maximum parallel configuration (panels)	9.5 ≈ 10	8.1 ≈ 8	11.7 ≈ 12	5.17 ≈ 5

Table 8. Calculation of Series-Parallel Configuration for 100 W Solar Panels

Specification	Monocrystalline		Polycrystalline	
	Sun-Earth DXM5-36P	Luxor LX-100M	Eastech Solar ESF-100PC	Canadian Solar 100 W
Open Circuit Voltage (Voc) (V)	22.70	21.60	22.60	21.90
Maximum Power Voltage (Vmp) (V)	18.50	18.70	18.30	17.40
Maximum Power Current (Imp) (A)	5.41	5.39	5.47	7.46
The following data is extracted from the inverter specifications:				
Minimum Sistem Voltage (Vmin) (V)	1100	1100	1100	600
Maximum Sistem Voltage (Vmax) (V)	200	200	200	80
Serial-Parallel Configuration of Solar Panels				
Minimum series configuration (Vmin/Vmp) (panels)	10.8 ≈ 11	10.8 ≈ 11	10.9 ≈ 11	4.5 ≈ 5
Maximum series configuration (Vmax/Voc) (panels)	48.4 ≈ 48	50.9 ≈ 51	48.6 ≈ 49	27.3 ≈ 27
Maximum parallel configuration (panels)	11.0 ≈ 11	11.1 ≈ 11	10.9 ≈ 11	8 ≈ 8

The Initial Investment Cost (C)

Table 9 simulates the initial investment costs related to the development of a Solar Power Plant currently being planned for a capacity of 485 W, and Table 10 for 100 W. The table provides a comprehensive breakdown of the expenses incurred in constructing the Solar Power Plant using two photovoltaic systems, Monocrystalline and Polycrystalline, with system capacities of 485 W and 100 W, respectively. By utilizing the table, we can gain a better understanding of the estimated expenses required to carry out the construction of the Solar Power Plant (Shuai et al., 2019). The information in this table offers a clear overview of the financial aspects associated with using photovoltaic technology in developing the Solar Power Plant.

Moreover, the comprehensive breakdown of expenses offered in the tables assists in assessing the feasibility and cost-effectiveness of utilizing photovoltaic technology in the Solar Power Plant development. It allows stakeholders to analyze the project's financial viability and identify areas where cost optimization may be necessary.

Maintenance And Operational Costs (M_{pwo})

The annual maintenance and operational costs for the Solar Power Plant are calculated to be 1% to 2% of the initial investment cost. This percentage includes expenses for solar panel cleaning, maintenance work, and equipment component inspections (Hernández-Callejo et al., 2019). This study sets the maintenance and operational costs at 1% of the total initial investment (Khajavi et al., 2014). Consequently, the maintenance and operational costs are relatively higher, based on the type and capacity of the Solar Power Plant.

Table 9. The Initial Investment Cost Capacity 485 W

Types	Brand	Components	Qty	Unit Price (IDR)	Total Price (IDR)
Monocrystalline	Canadian Solar 485W	Solar Panel	16	3,164,000	50,624,000
		Sungrow SG40CX Inverter	1	21,250,000	21,250,000
		Installation and other Costs		7,187,400	7,187,400
		Total			71,874,000
	Sun Power	Solar Panel	16	3,064,000	49,024,000
		Sungrow SG40CX Inverter	1	21,250,000	21,250,000
		Installation and other Costs		6,952,000	6,952,000
		Total			69,524,000
Polycrystalline	GCL P6/96	Solar Panel	15	3,064,000	45,960,000
		Sungrow SG40CX Inverter	1	21,250,000	21,250,000
		Installation and other Costs		6,721,000	6,721,000
		Total			67,210,000
	VSG 505 Ertex Solar	Solar Panel	15	2,960,000	44,250,000
		Sungrow SG40CX Inverter	1	21,250,000	21,250,000
		Installation and other Costs		6,475,000	6,475,000
		Total			64,750,000

Table 10. The Initial Investment Cost Capacity 100 W

Types	Brand	Components	Qty	Unit Price (IDR)	Total Price (IDR)
Mono-crystalline	Sun-Earth DXM5-36P	Solar Panel	76	1,000,000	76,000,000
		Sofar 10000TL-G2 Inverter	1	6,000,000	6,000,000
		Installation and other Costs		8,200,000	8,200,000
		Total			82,000,000
	Luxor LX-100M	Solar Panel	80	900,000	72,000,000
		Sofar 11TL-X Inverter	1	12,000,000	12,000,000
		Installation and other Costs		8,400,000	8,400,000
		Total			84,000,000
Poly-crystalline	Eastech Solar ESF-100PC	Solar Panel	16	980,000	15,680,000
		Solarmax 1000SP Inverter	1	1,200,000	1,200,000
		Installation and other Costs		1,688,000	1,688,000
		Total			16,880,000
	Canadian Solar 100W	Solar Panel	18	900,000	14,400,000
		Sunny Boy 1.5 Inverter	1	1,200,000	1,200,000
		Installation and other Costs		1,560,000	1,560,000
		Total			15,600,000

Life Cycle Cost (Lcc)

The life cycle cost of a solar PV system is determined by the present value of the total system costs, including the initial investment cost (C) and the long-term costs for maintenance, operation, and component replacement (Mpwo) (Abu-Rumman et al., 2020). In this study, the solar PV system is assumed to operate for 15 years (Numbi & Malinga, 2017), based on the warranty provided by the solar panel manufacturer. The discount rate (i) used to calculate the present value is 4%, based on the interest rate of the Bank of Indonesia, as shown in Eq 1 and 2. With the calculation and variables n = 15 and i = 0.12, *P: Present Value,* M_{pwo}*: Maintenance and Operational Costs, LCC: Life Cycle Cost, C: Investment Cost.* To calculate the present value of the maintenance and operational costs (Mpwo) of the solar PV system over the 15-year project lifespan with a discount rate of 12%.

$$P = M_{pwo} \frac{(1+i)^n - 1}{i(1+i)^n} \quad (1)$$

$$LCC = C + P \quad (2)$$

Table 11 explains the magnitude of operation and maintenance costs; routine operations should be planned comprehensively and clearly defined to ensure the efficient execution of all routine tasks, including items such as (1) monitoring the power meter, (2) monitoring the weather station, including data logger, global pyranometer, hygrometer, barometer, ambient and module temperature sensor; (3) monitoring the communication and CCTV system; and (4) monitoring cabinets, protections, cables, strings, thermographic images, and switches.

Table 11. Maintenance and Operational Costs

Capacity	Types	Brand	Investation (C) (IDR)	Maintenance and Operational Costs -1% (M_{pwo}) (IDR)
485W	Monocrystalline	Canadian Solar 485W	71,874,000	718,740
		Sun Power	69,524,000	695,240
	Polycrystalline	GCL P6/96	67,210,000	672,100
		VSG 505 Ertex Solar	64,750,000	647,500
100W	Monocrystalline	Sun-Earth DXM5-36	82,000,000	820,000
		Luxor LX-100M	84,000,000	840,000
	Polycrystalline	Eastech Solar ESF-100PC	16,880,000	168,800
		Canadian Solar 100W	15,600,000	156,000

Table 12. Life Cycle Cost

Capacity	Types	Brand	P (IDR)	LCC (IDR)
485W	Monocrystalline	Canadian Solar 485W	4,743,684	76,617,684
		Sun Power	4,588,584	74,112,584
	Polycrystalline	GCL P6/96	4,435,860	71,645,860
		VSG 505 Ertex Solar 485W	4,273,500	69,023,500
100W	Monocrystalline	Sun-Earth DXM5-36P	5,412,000	87,412,000
		Luxor LX-100M	5,544,000	89,544,000
	Polycrystalline	Eastech Solar ESF-100PC	1,114,080	17,994,080
		Canadian Solar 100W	1,029,600	16,629,600

The life cycle cost of the solar power system in Table 12 yields the total cost that encompasses the initial investment cost to build the system (C) and the long-term costs for maintenance, operation, and component replacement (Mpwo). It means calculating all the expenses related to the construction, operation, and maintenance of the system in present value terms. These calculations assist in assessing investment efficiency, and help system owners determine when component replacements may be necessary and when the system will be profitable overall during its lifespan.

CONCLUSION

The research analyzed the solar power generation requirements based on photovoltaic specifications and considered the economic factors in selecting photovoltaic systems. The simulation results showed that the 485Wp monocrystalline photovoltaic system, using Canadian Solar HiKu5 Mono PERC panels, achieved the highest output of 8 kWp with 15 panels. The 100 Wp monocrystalline photovoltaic system, using Sun-Earth DXM5-36P panels, achieved the highest output of 4kWp with 36 panels. The economic simulation indicated that the 485Wp monocrystalline system, using Canadian Solar HiKu5 Mono PERC panels, had the highest economic value of IDR 71,874,000 and produced 2,920 kWp per year. Similarly, the 100Wp monocrystalline system, using Sun-Earth DXM5-36P panels, had the highest economic value of IDR 82,000,000 and produced 1,460 kWp per year. Monocrystalline panels with capacities of 485 Wp and 100 Wp are preferred due to their durability, although they are generally more expensive than polycrystalline panels.

REFERENCES

Abu-Rumman, A. K., Muslih, I., & Barghash, M. (2017). Life cycle costing of PV generation system. *Journal of applied research on industrial engineering*, *4*(4), 252-258.

Archila, L. M. P., Rodríguez, J. D. B., & Correa, R. (2021). Implicit modelling of series-parallel photovoltaic arrays using double-diode model and its solution. *Solar Energy*, *214*, 131-137.

Calcabrini, A., Muttillo, M., Weegink, R., Manganiello, P., Zeman, M., & Isabella, O. (2021). A fully reconfigurable series-parallel photovoltaic module for higher energy yields in urban environments. Renewable Energy, 179, 1–11.

Cotfas, D. T., Cotfas, P. A., & Machidon, O. M. (2018). Study of temperature coefficients for parameters of photovoltaic cells. International Journal of Photoenergy, 2018.

Dubey, S., Sarvaiya, J. N., & Seshadri, B. (2013). Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World A Review. Energy Procedia, 33, 311–321.

Fais, B., Blesl, M., Fahl, U., & Voß, A. (2014). Comparing different support schemes for renewable electricity in the scope of an energy systems analysis. Applied Energy, *131*, 479–489.

Gonz, D., Garc, I., & Dieste-velasco, M. I. (2021). applied sciences Photovoltaic Prediction Software : Evaluation with Real Data.

González-Peña, D., García-Ruiz, I., Díez-Mediavilla, M., Dieste-Velasco, M. I., & Alonso-Tristán, C. (2021). Photovoltaic prediction software: evaluation with real data from northern Spain. *Applied Sciences*, *11*(11), 5025.

Gurupira, T., & Rix, A. (2017). Pv simulation software comparisons: Pvsyst, nrel sam and pvlib. In *Conf.: saupec*.

Hasudungan, H. W. V., & Sabaruddin, S. S. (2018). Financing Renewable Energy in Indonesia: A CGE Analysis of Feed-In Tariff Schemes.

Bulletin of Indonesian Economic Studies, 54(2), 233–264.

Hernández-Callejo, L., Gallardo-Saavedra, S., & Alonso-Gómez, V. (2019). A review of photovoltaic systems: Design, operation and maintenance. Solar Energy, 188, 426–440.

Hidayat, F., Winardi, B., & Nugroho, A. (2019). Analisis Ekonomi Perencanaan Pembangkit Listrik Tenaga Surya (Plts) Di Departemen Teknik Elektro Universitas Diponegoro. Transient, 7(4), 875.

Jäger-waldau, A. (2020). Snapshot of Photovoltaics—February 2020. February.

Khajavi, S. H., Partanen, J., & Holmström, J. (2014). Additive manufacturing in the spare parts supply chain. *Computers in industry*, *65*(1), 50-63.

Kumar, R., Rajoria, C. S., Sharma, A., & Suhag, S. (2021). Design and simulation of standalone solar PV system using PVsyst Software: A case study. Materials Today: Proceedings, 46, 5322–5328.

Mengi-Dinçer, H., Ediger, V., & Yesevi, G. (2021). Evaluating the International Renewable Energy Agency through the lens of social constructivism. Renewable and Sustainable Energy Reviews, 152, 111705.

Numbi, B. P., & Malinga, S. J. (2017). Optimal energy cost and economic analysis of a residential grid-interactive solar PV system- case of eThekwini municipality in South Africa. Applied Energy, *186*, 28–45.

Ponce-Alcantara, S., Connolly, J. P., Sanchez, G., Miguez, J. M., Hoffmann, V., & Ordas, R. (2014). A statistical analysis of the temperature coefficients of industrial silicon solar cells. Energy Procedia, 55, 578–588.

Salmi, M., Baci, A. B., Inc, M., Menni, Y., Lorenzini, G., & Al-Douri, Y. (2022). Desing and simulation of an autonomous 12.6 kW solar plant in the Algeria's M'sila region using PVsyst software. Optik, 262, 169294.

Santiago, I., Trillo-Montero, D., Moreno-Garcia, I. M., Pallarés-López, V., & Luna-Rodríguez, J. J. (2018). Modeling of photovoltaic cell temperature losses: A review and a practice case in South Spain. Renewable and Sustainable Energy Reviews, 90, 70–89.

Shuai, J., Cheng, X., Ding, L., Yang, J., & Leng, Z. (2019). How should government and users share the investment costs and benefits of a solar PV power generation project in China? Renewable and Sustainable Energy Reviews, 104, 86–94.

Shukla, A. K., Sudhakar, K., & Baredar, P. (2017). Renewable energy resources in South Asian countries: Challenges, policy and recommendations. Resource-Efficient Technologies, 3(3), 342–346.

Suripto, H., & Fathoni, A. (2021). Analisis Kelayakan Pembangkit Listrik Tenaga Surya; sebuah review berdasarkan data histori, metode analisis, dan nilai ekonomi. *Aptek*, 33-41.

Tabanjat, A., Becherif, M., & Hissel, D. (2015). Reconfiguration solution for shaded PV panels using switching control. Renewable Energy, 82, 4–13.