Solar power plant on the rooftop of the Diponegoro University Rectorate: a technical and economic study

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ABSTRACT

Diponegoro University's Rectorate building uses electricity from the National Electricity Company with a S2 social subscription type of 105 kVA. The designed solar power plant has a capacity of 25 kW, or 25% of the installed electrical capacity. This research aims to compare the solar panels and inverter configurations that will be used in solar power plants. Moreover, this study aims to find out which configuration will provide the best results and the biggest savings. Technical analysis is carried out with the photovoltaic system (PVSyst) software to calculate the energy produced by solar panels, inverter losses, and other results. On the other hand, economic analysis is carried out with RetScreen software to calculate net present value (NPV), benefit cost ratio (BCR), and payback period (PP). Based on the PVSyst simulation results, the estimated energy production for each variant is 39,684 kWh; 39,633 kWh; 39,507 kWh; and 39,446 kWh. The first variant has the biggest performance ratio value of 84.1%. Based on the Retscreen calculation result, the third variant has an NPV value of $22,698, a BCR value of 2, and a PP of 8.7 years, which has the best result and the highest advantages.

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1. INTRODUCTION

Solar energy is the most promising and environmentally friendly energy source, and it is also considered renewable energy. In addition, solar energy is also an alternative solution to reduce fossil energy [1], [2]. The potential for solar energy in Indonesia reaches 207,898 MW due to the relatively high amount of solar radiation of 4.80 kWp/m²/day [3], [4]. Until the end of July 2022, the total capacity of installed solar power plants throughout Indonesia had only reached 62 MW, while the target set by the Indonesian government is 3,600 MW in 2025 [2], [4].

The Indonesian government has proposed revising regulation of the Minister of Energy and Mineral Resources number 49 of 2018 concerning the use of rooftop solar power generation systems by consumers of the National Electricity Company [5], [6] into a Regulation of the Minister of Energy and Mineral Resources Daya Mineral number 26 of 2021 concerning rooftop solar power plants connected to an electric power network holders of business licenses. This results in an increase in the selling price from 65% to 100% of the existing price at the National Electricity Company. Through this regulation, the government hopes to motivate and encourage the community to install solar power plants [5], [7], [8]. The high potential of solar energy in Indonesia, as well as government support and regulation, make solar energy a viable option for meeting future electricity needs [8], [9].

There are 3 types of solar power plant configurations: on-grid, off-grid, and hybrid systems [10], [11]. The on-grid system is a solar power generation system that is directly connected to the National Electricity Company network and the load, so that both the solar power plant and the National Electricity Company network can be the source of energy alternately [12]. The off-grid system is a solar power generation system that is connected only to the load, so that this system will alternately depend on battery support while unconnected to the load [13], [14]. The hybrid system is a combination of on-grid and off-grid systems where the system can be connected to the power grid, battery, and load so that the load can use electrical energy from the National Electricity Company when the battery is empty and the solar power plant does not produce electrical energy [15].

In this study, the author will conduct a technical analysis and economic feasibility of a solar power plant with an on-grid system in the Diponegoro University Rectorate building. The Diponegoro University Rectorate building still uses electricity from National Electricity Company with a social S2 subscription type with power rating of 105 kVA. The on-grid system is chosen because of a policy revision from the Indonesian government which indicated that people could sell electricity to National Electricity Company at 100% price [16].

The other advantage of the on-grid system is that excess electrical energy can be sold to the National Electricity Company [14], [17]. Meanwhile, the weakness of this system is its inability to transmit electrical energy to the load while experiencing a power outage from the power grid because the inverter will automatically turn off when there is no incoming voltage from the power grid [17], [18]. The electric power generated from the solar power plant during a power outage will be lost if there is no storage battery in the solar power plant [17], [19]. This causes considerable energy losses and will result in an increase in the payback period (PP) for solar power plants [8], [13], [17], [19]. The purposes of this study are to compare the configuration of solar panels and inverters and find out which configuration will give the best results and provide the biggest savings.

2. METHOD

The method used in this study are determining the research location, collecting data, determining component specifications, designing in photovoltaic system (PVSyst) and retscreen software, and analyzing the simulation results [20], [21]. Technical analysis is carried out with the PVSyst software to determine the energy produced by solar panels, inverter losses, and others [21], [22]. Economic analysis is performed using Retscreen software to determine net present value (NPV), benefit cost ratio (BCR) and PP [23], [24].

2.1. Research location

Figure 1 shows the location for installing the solar power plant in this study. Coordinates of Diponegoro University's Rectorate building is -7.0488; 110.4380. Figure 2 shows building visualization used for installation of solar power plant which will be carried out on the roof of the building.

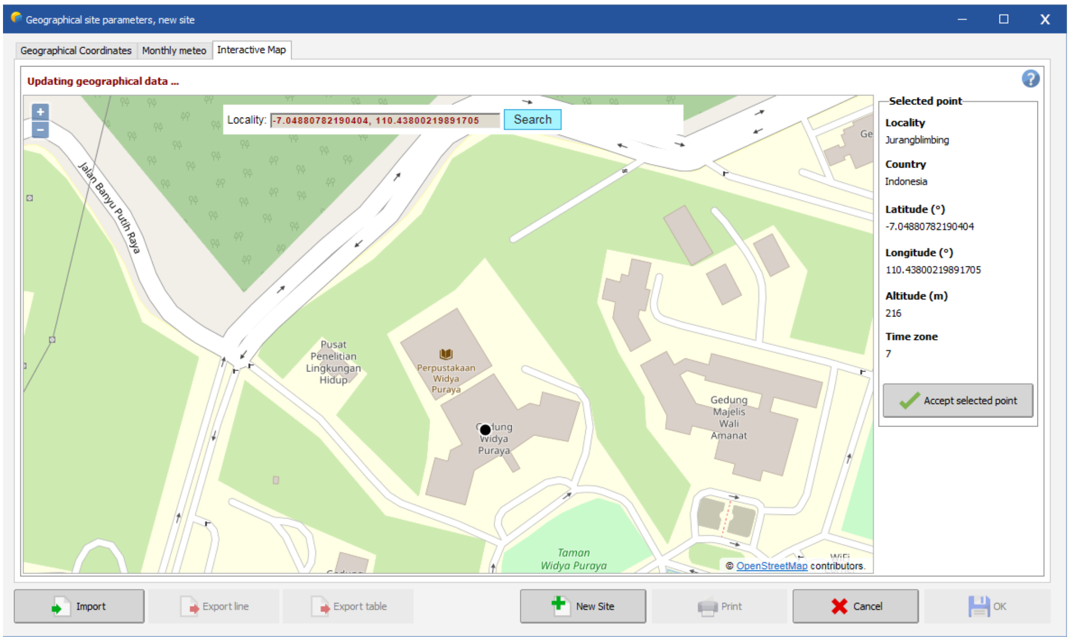

Figure 1. Research location map

Figure 2. Diponegoro University's Rectorate building visualization

2.2. Electrical load profile data

Daily load data at the research location is generated periodically to calculate absolute load profile data. The research location has an installed electricity capacity of 105 kVA. Figure 3 shows weekdays load profile and Figure 4 shows the weekend load profile. Figure 3 shows the daily load on weekdays of 0.822 MWh/day and Figure 4 shows the daily load on weekends of 0.124 MWh/day. Within a month, the total load in the Rectorate building is 28.4 MWh/month.

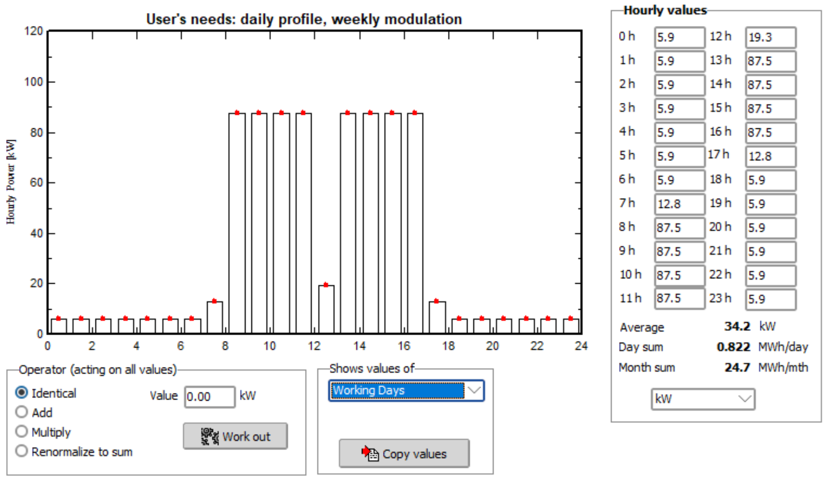

Figure 3. Load profile on weekdays

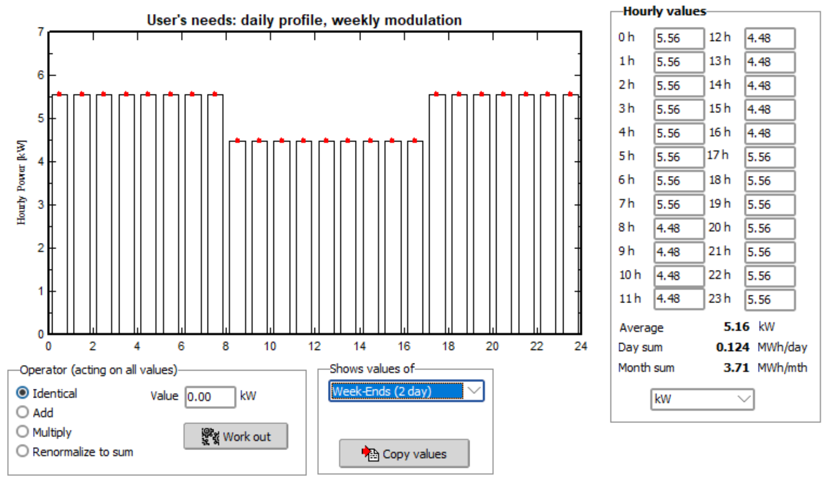

Figure 4. Load profile on weekend

2.3. Solar radiation data

According to National Aeronautics and Space Administration (NASA) prediction of worldwide energy resources data, solar radiation data in 2021 at Diponegoro University Rectorate Building which contains global horizontal irradiation (GHI) is 5.27 kWh/m²/day and horizontal diffuse irradiation (HDI) value of 2.23 kWh/m²/day [20], [25]. This data can be used to generate potential results for this research. Table 1 shows the solar radiation data, temperature and wind velocity in research location per months.

Table 1. Solar radiation data in research location

Month	GHI (kWh/m²/month)	HDI (kWh/m²/month)	Temperature (ºC)	Wind velocity (m/s)
January	133.92	93.93	25.90	2.98
February	136.92	80.36	25.68	3.78
March	167.09	90.52	26.27	2.09
April	149.10	72.30	26.32	2.43
May	138.57	71.92	26.75	2.37
June	157.80	66.30	26.26	2.13
July	166.16	58.59	25.94	2.85
August	174.22	70.99	26.87	3.19
September	166.80	75.60	27.26	3.10
October	138.57	94.55	27.73	2.43
November	145.20	88.20	26.72	1.70
December	153.76	95.79	26.82	1.99

2.4. Solar panel orientation

When the absorbing surface of solar PV modules and panels is perpendicular to the incoming sunlight, they perform at their best. Sun position in the sky or orientation angle of the solar panel depends on the azimuth and zenith values. Azimuth is the sun's compass angle as it crosses the sky from East to West throughout the course of the day. Zenith is the angle at which the sun appears when seen from the ground or the horizon. For fixed installation, tilt angle (refers to zenith) is the angle of the photovoltaic module from the horizontal plane for fixed installation. According to the rooftop orientation at research location, solar power plant configuration simulation will use tilt plane of 30º and azimuth of –100º. Solar panel orientation setting in PVSyst is shown in Figure 5.

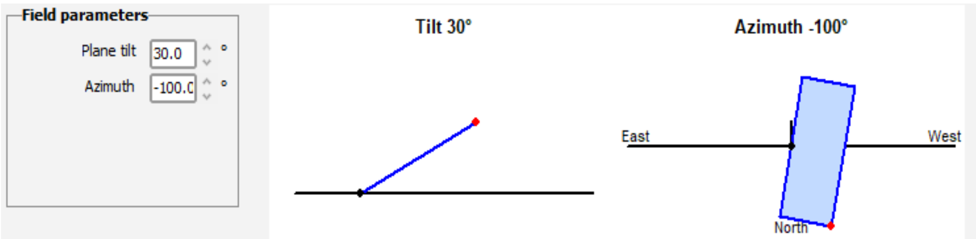

Figure 5. Solar panel orientation in research location

2.5. Solar power plant configuration

A simple circuit for a solar power plant is shown in Figure 6. The energy generated by solar panels in direct current electricity form (E_Array) is converted into alternated electricity using an inverter. Electrical energy from the inverter (E_Solar) will be used directly by the load (E_Used). When the electrical energy from the inverter is insufficient to the target (E_Needed), electricity from the National Electricity Company grid will increase the energy output of the inverter to meet user needs (E_Import). When the electrical energy from the inverter is higher than the load requirements, the excess energy will be sold to the grid (National Electricity Company) (E_Export) [26]–[28].

Solar panel and inverter play important role in solar power plant. Each section has two options. Monocrystalline and polycrystalline solar panels with a power of 410 Wp are the elective choices in this study. This applies to inverters with a maximum efficiency rate of over 98%. The chosen solar power generator will be inputted into the PVSyst software. The solar power plant that will be designed in the study has a capacity of 25 kW or 25% of the electricity capacity installed at the research location. The choice of alternative components used for simulation in the PVSyst software is shown in Tables 2 and 3. According to solar panel and inverter choices shown in Tables 2 and 3, there is 4 variants obtained that will be simulated. Those variants are shown in Table 4.

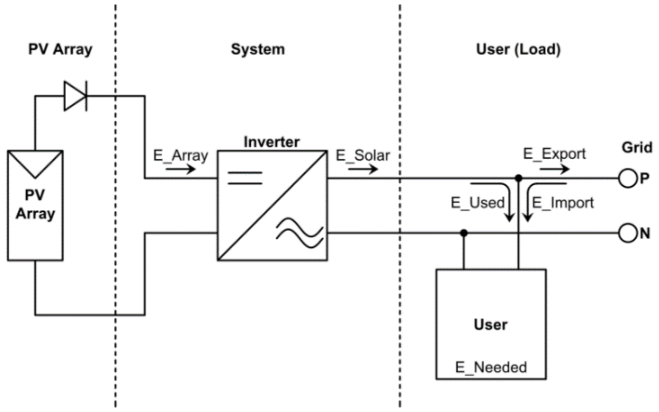

Figure 6. Simplified sketch of solar power plant

Table 2. Solar panel specifications

Parameter	First solar panel	Second solar panel
Manufacture	Risen solar	CSI solar
Model	RSM-144-6-410-M	CS3W-410P HE
Type	Monocrystalline	Polycrystalline
Power maximum (P_{max})	410 Wp	410 Wp
Open circuit voltage (V_{oc})	48.90 V	47.60 V
Short circuit current (I_{sc})	10.70 A	11.06 A
Maximum point voltage (V_{mp})	40.65 V	39.10 V
Maximum point current (I_{mp})	10.10 A	10.49 A
Module efficiency	23.56%	20.67%
Dimension (mm×mm×mm)	2,015×996×40	2,108×1,048×40
Price	$175.00	$154.59

Table 3. Inverter specifications

Parameter	First inverter	Second inverter
Manufacture	INVT solar technology	SMA
Model	BG25KTR	Sunny Tripower 25000TL-30
Input DC		
Maximum solar array power (P_{DC})	26,000 kW	25,550 W
Maximum DC voltage (V_{DC})	1,000 V	1,000 V
Maximum input current (I_{DC})	60 A	66 A
MPPT voltage range (V_{MPPT})	280-800 V	390-800 V
Output AC		
Maximum output power (P_{AC})	25,000 W	25,000 W
Grid voltage range (V_{AC})	230/380 V	220/380 V
Maximum output current (I_{AC})	38.00 A	36.20 A
General data		
Maximum efficiency	98.40%	98.30%
Price	$1,801.35	$2,688.10

Table 4. Solar power plant configuration

Variants	Solar panel	Inverter	Array configuration
First variant	RSM-144-6-410-M	BG25KTR	Module in series=17
	Voc=48.9 V	Max Vin=1,000 V	Number of strings=4
	Isc=10.7 A	Max Iin=60 A	Voc=809.2 V
			Isc=44.24 A
Second variant	RSM-144-6-410-M	Sunny Tripower 25000TL-30	Module in series=17
	Voc=48.9 V	Max Vin=1,000 V	Number of strings=4
	Isc=10.7 A	Max Iin=66 A	Voc=809.2 V
			Isc=44.24 A
Third variant	CS3W-410P HE	BG25KTR	Module in series=17
	Voc=47.60 V	Max Vin=1,000 V	Number of Strings=4
	Isc=11.06 A	Max Iin=60 A	Voc=809.2 V
			Isc=44.24 A
Fourth variant	CS3W-410P HE	Sunny Tripower 25000TL-30	Module in series=17
	Voc=47.60 V	Max Vin=1,000 V	Number of strings=4
	Isc=11.06 A	Max Iin=66 A	Voc=809.2 V
			Isc=44.24 A

3. RESULTS AND DISCUSSION

3.1. Technical analysis

The PVSyst simulation results are shown in Figure 7. It can be seen on the figures that the first variant in Figure 7(a) is able to generate 39,684 kWh of electricity, the second variant in Figure 7(b) of 39,633 kWh, the third variantvariant in Figure 7(c) of 39,507 kWh, and the fourth variant in Figure 7(d) of 39,446 kWh. PVSyst simulation comparison for each variant is shown in Table 5.

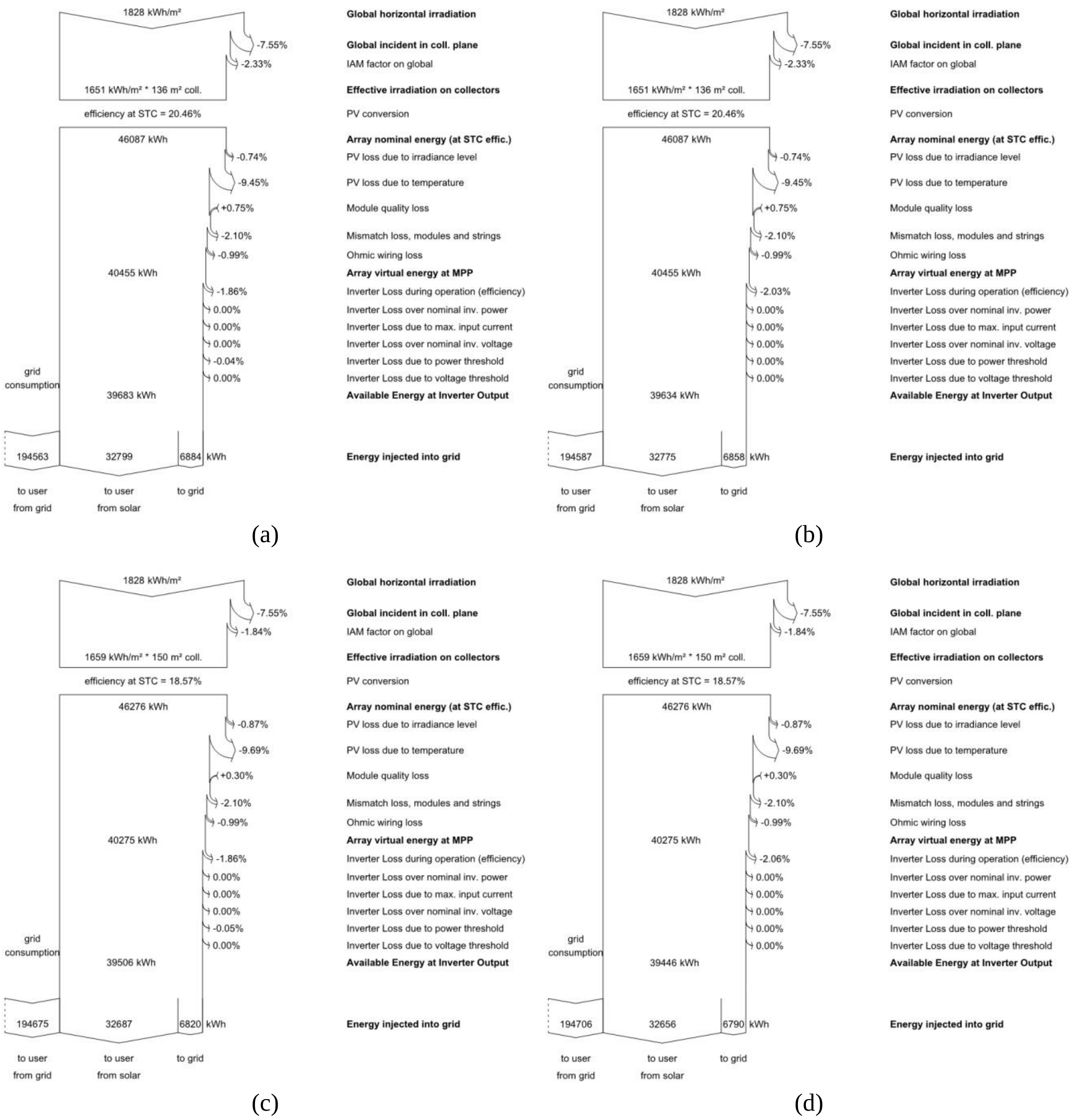

Figure 7. PVSyst simulation result (a) first variant, (b) second variant, (c) third variant, and (d) fourth variant

Table 5. PVSyst simulation comparison for each variant

Variants	E_Array (kWh)	E_Solar (kWh)	E_Used (kWh)	Inverter losses (kWh)	Inverter efficiency (%)	Performance ratio (%)
First variant	40,454	39,684	32,799	771	98.10	84.2
Second variant	40,454	39,633	32,775	821	97.97	84.1
Third variant	40,275	39,507	32,687	768	98.09	83.8
Fourth variant	40,275	39,446	32,656	829	97.94	83.7

Table 5 shows that the solar panels in the 1st variant and 2nd variant (RSM-144-6-410-M) can generate 40,454 kWh of energy. Those variants have higher value than the energy produced by solar panels in the 3rd variant and 4th variant (CS3W-410P HE) of 40,275 kWh. The RSM-144-6-410-M solar panel has a module efficiency of 23.56% and a surface area of 136 m², while the CS3W-410P HE solar panel has a module efficiency of 20.67% and a surface area of 152 m². This shows that monocrystalline solar panels have greater efficiency and are able to produce more energy than polycrystalline solar panels [29], [30]. In addition, monocrystalline solar panels have a higher concentration of basic materials than polycrystalline solar panels [30].

Inverter efficiency in the 1st variant and 3rd variant (BG25KTR) is 98.10% and 98.09% with losses of 771 kWh and 768 kWh. The efficiency value of the inverter is greater than the efficiency value of the inverter in the 2nd variant and 4th variant (sunny Tripower 25000TL-30) of 97.97% and 97.94% and losses value of 821 kWh and 829 kWh. This shows that the BG25KTR inverter has greater efficiency value and fewer losses than the sunny Tripower 25000TL-30 inverter. In accordance with the inverter specifications where the BG25KTR inverter has a maximum efficiency value of 98.40% and the sunny Tripower 25000TL-30 inverter has a maximum efficiency value of 98.30%. Based on the results of this simulation, it is found that the solar power plant configuration with best result is the first variant with the RSM-144-6-410-M solar panel and the BG25KTR inverter. This is due to its largest performance ratio value of 84.2%.

3.2. Economic feasibility

Economic analysis of the four variants is calculated with software Retscreen based on initial investment value, operational and maintenance costs, and annual savings [24], [31], [32]. The inflation rate in Indonesia may affect the value of money in the future, so it is also included in the simulation [32]. Based on data from *Bank Indonesia*, inflation data in Indonesia in October 2022 is 5.71% [18], [33]. The parameters of economic feasibility are NPV, BCR, and discounted payback period (DPP) [23], [24]. The amount of initial investment costs and operational and maintenance costs for each variant is shown in Tables 6-9.

The amount of initial investment costs and operational and maintenance costs in the 1st variant is $24,714.30 and $240.52, the 2nd variant is $25,601.04 and $249.38, the 3rd variant is $23,326.57 and $226.64, the 4th variant is $24,213.31 and $235.51. The 2nd variant has the biggest initial investment cost, while on the other hand, the 3rd variant has the smallest investment cost. The value of energy used for loads and energy sold to National Electricity Company is also obtained with PVSyst software simulation [34]. The selling price of electricity for S2 social customers with a power capacity of 105 kVA is $0.05724/kWh. The saving data obtained for each variant is shown in Table 10.

Table 6. Initial investment and operational cost on 1st variant

Component	Amount	Unit	Price (USD) ($)	Total price (IDR) ($)	Operational and maintenance (1%) ($)
Solar panel RSM-144-6-410-M	68	Module	175.00	11,899.74	119.00
Inverter BG25KTR	1	Piece	1,801.35	1,801.35	18.01
Solar panel mounting	1	set	6,381.52	6,381.52	63.82
Cable	1	set	2,253.45	2,253.45	22.53
Protection	1	set	1,715.65	1,715.65	17.16
Service and others	1	set	662.59	662.59	
Total				24,714.30	240.52

Table 7. Initial investment and operational cost on 2nd variant

Component	Amount	Unit	Price (USD) ($)	Total price (idr) ($)	Operational and maintenance (1%) ($)
Solar panel RSM-144-6-410-M	68	Module	175.00	11,899.74	119.00
Inverter sunny Tripower 25000TL-30	1	Piece	2,688.10	2,688.10	26.88
Solar panel mounting	1	set	6,381.52	6,381.52	63.82
Cable	1	set	2,253.45	2,253.45	22.53
Protection	1	set	1,715.65	1,715.65	17.16
Service and others	1	set	662.59	662.59	
Total				25,601.04	249.38

Table 8. Initial investment and operational cost on 3rd variant

Component	Amount	Unit	Price (USD) ($)	Total price (IDR) ($)	Operational and maintenance (1%) ($)
Solar panel CS3W-410P HE	68	Module	154.59	10,512.01	105.12
Inverter BG25KTR	1	Piece	1,801.35	1,801.35	18.01
Solar panel mounting	1	set	6,381.52	6,381.52	63.82
Cable	1	set	2,253.45	2,253.45	22.53
Protection	1	set	1,715.65	1,715.65	17.16
Service and others	1	set	662.59	662.59	
	Total			23,326.57	226.64

Table 9. Initial investment and operational cost on 4th variant

Component	Amount	Unit	Price (USD) ($)	Total price (IDR) ($)	Operational and maintenance (1%) ($)
Solar panel CS3W-410P HE	68	Module	154.59	10,512.01	105.12
Inverter sunny Tripower 25000TL-30	1	Piece	2,688.10	2,688.10	26.88
Solar panel mounting	1	set	6,381.52	6,381.52	63.82
Cable	1	set	2,253.45	2,253.45	22.53
Protection	1	set	1,715.65	1,715.65	17.16
Service and others	1	set	662.59	662.59	
Total				24,213.31	235.51

Table 10. Saving results of each variant

Variants	E_Used		E_Export		Total saving	
	kWh	USD ($)	kWh	USD ($)	kWh	USD ($)
First variant	32,799	1,877.42	6,884.5	394.07	39,986	2,271.49
Second variant	32,775	1,876.04	6,858.2	392.56	39,930	2,268.61
Third variant	32,687	1,871.01	6,819.6	390.35	39,808	2,261.36
Fourth variant	32,656	1,869.23	6,790.2	388.67	39,741	2,257.90

The 1st variant provides the biggest saving value compared to the other variants. This is in accordance with the technical analysis that has been carried out where the first variant has the best results. The Retscreen software simulation is carried out based on the initial investment data, operational and maintenance costs, and annual savings calculation [24], [31], [32]. The Retscreen simulation result is shown in Figure 8. It can be seen on the figures that the first variant in Figure 8(a) results in a simple PP calculation of 12.2 years, the second variant in Figure 8(b) of 12.7 years, the third variant in Figure 8(c) of 11.5 years, and the fourth variant in Figure 8(d) of 12 years. Retscreen simulation result for each variant is shown in Table 11.

Financial viability		
Pre-tax IRR - equity	%	11.3%
Pre-tax MIRR - equity	%	5.8%
Pre-tax IRR - assets	%	11.3%
Pre-tax MIRR - assets	%	5.8%
Simple payback	yr	12.2
Equity payback	yr	9.1
Net Present Value (NPV)	$	21,225
Annual life cycle savings	$/yr	1,632
Benefit-Cost (B-C) ratio		1.9
Debt service coverage		No debt
GHG reduction cost	$/tCO₂	No reduction

(a)

Financial viability		
Pre-tax IRR - equity	%	10.8%
Pre-tax MIRR - equity	%	5.6%
Pre-tax IRR - assets	%	10.8%
Pre-tax MIRR - assets	%	5.6%
Simple payback	yr	12.7
Equity payback	yr	9.4
Net Present Value (NPV)	$	20,072
Annual life cycle savings	$/yr	1,543
Benefit-Cost (B-C) ratio		1.8
Debt service coverage		No debt
GHG reduction cost	$/tCO₂	No reduction

(b)

Financial viability		
Pre-tax IRR - equity	%	12.1%
Pre-tax MIRR - equity	%	6.1%
Pre-tax IRR - assets	%	12.1%
Pre-tax MIRR - assets	%	6.1%
Simple payback	yr	11.5
Equity payback	yr	8.7
Net Present Value (NPV)	$	22,698
Annual life cycle savings	$/yr	1,745
Benefit-Cost (B-C) ratio		2
Debt service coverage		No debt
GHG reduction cost	$/tCO₂	No reduction

(c)

Financial viability		
Pre-tax IRR - equity	%	11.5%
Pre-tax MIRR - equity	%	5.9%
Pre-tax IRR - assets	%	11.5%
Pre-tax MIRR - assets	%	5.9%
Simple payback	yr	12
Equity payback	yr	9
Net Present Value (NPV)	$	21,532
Annual life cycle savings	$/yr	1,655
Benefit-Cost (B-C) ratio		1.9
Debt service coverage		No debt
GHG reduction cost	$/tCO₂	No reduction

(d)

Figure 8. Retscreen simulation result (a) first variant, (b) second variant, (c) third variant, and (d) fourth variant

Table 11. Retscreen simulation result of each variant

Variants	NPV (USD) ($)	BCR	PP (years)
First variant	21,225	1.9	9.1
Second variant	20,072	1.8	9.4
Third variant	22,698	2.0	8.7
Fourth variant	21,532	1.9	9.0

Based on the results of the Retscreen simulation, it is found that the NPV value of all variant produced positive values and the BCR value obtained is more than 1. This shows that the four variants are economically feasible to be implemented [35]. The largest NPV value is in the 3rd variant of $22,698. The biggest BCR is in the 3rd variant of 2.0 and the smallest PP is in the 3rd variant of 8.7 years. Therefore, it can be concluded that the 3rd variant (CS3W-410P HE solar panel with BG25KTR inverter) gives the best results compared to the other variants. This is because the investment costs and operational and maintenance costs in the 3rd variant are lower than the other variants.

4. CONCLUSION

Diponegoro University Rectorate building is still powered by National Electricity Company and has a power rating of 105 kVA. This building's solar power plant has a capacity of 25 kW, or 25% of the total installed electrical capacity. The first variant uses the RSM-144-6-410-M solar panel with the BG25KTR inverter; the second uses the RSM-144-6-410-M solar panel with the sunny Tripower 25000TL-30 inverter; the third uses the CS3W-410P HE solar panel with the BG25KTR inverter; and the fourth uses the RSM-144-6-410-M solar panel with the sunny Tripower 25000TL-30 inverter. The estimated energy production for each variant is 39,684 kWh, 39,633 kWh, 39,507 kWh, and 39,446 kWh, based on the PVSyst simulation findings. Monocrystalline solar panels produce more energy and are more efficient than polycrystalline solar panels. The sunny Tripower 25000TL-30 inverter outperforms the BG25KTR inverter in terms of efficiency and losses. The first variant, with the RSM-144-6-410-M solar panel and BG25KTR inverter, produces the best results. This is corroborated by the first variant having the highest performance ratio value of 84.2%. Based on the Retscreen simulation findings, it is discovered that the NPV value of all variants created positive values, and the BCR value acquired is larger than one. This demonstrates that the four alternatives are financially possible to adopt. As a consequence, the third variant (CS3W-410P HE solar panel with BG25KTR inverter) offers the best results and the largest benefits, with an NPV value of $22,698; a BCR value of 2.0; and a PP of 8.7 years.

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