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Technical and Economical Feasibility Analysis on Household-Scale Rooftop Solar Power Plant Design with On-Grid System in Semarang City

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Abstract: Utilizing rooftops as a solar power plant system on the grid can be an effective and efficient solution to reduce electricity bills. This research aims to design and analyze the potential of 1215 Wp solar power plant rooftop with on grid system household scale in terms of techno economy. Using each of the two alternatives to the main components of solar panels and inverters, there were 4 variations of the component configuration design in this study. Variation 1 uses Canadian solar panels with solax inverters. Variation 2 uses Canadian solar panels with so far inverters. Variation 3 uses risen solar panels with solax inverters. Variation 4 uses risen solar panels with sofar inverter. Through PVSyst 6.43 software, with an average radiation average of 5.48 kWh/m2/day, the potential energy production of each variation of 1215 Wp rooftop solar power plant household scale are 1873 kWh, 1893 kWh, 1865 kWh and 1885 kWh. The investment cost of 1215 Wp rooftop solar power plant ranges from IDR25,220,000-IDR27,020,000 with Net Present Value ranges from IDR15,309,805- IDR17,421,839, Benefit Cost Ratio ranges from 1,489-1,588, Payback period ranges from 10.38 – 11.02 years and Internal Rate of Return value ranges from 8.8-9.56%.
Keywords: *Benefit cost ratio, Internal rate of return, Net present value, Payback period, PVSyst 6.43, Solar Power Plant.*

1. Introduction

The demand for electricity has always grown from time to time compared to other energies. The electricity demand in Indonesia is projected to meet 2.214 TWh in 2050, or it can be said that the demand will increase for about 9 times from the electricity demand in 2018 in the amount of 254,6 TWh. The growth rate of electricity demand may reach an annual average score of 7% over the 2018-2050. The electricity demand during the projection period is relatively common with the largest portion of the household sector, industrial sector, commercial sector, transportation sector, and other sectors. The share of household electricity sector will increase from 49% in 2018 to 58% in 2050. This condition is primarily affected by the household growth number which may increase from 67 million in 2018 to approximately 80 million in 2050 [1, 2].

The decrease in fossil energy production especially petroleum and global commitments in reducing greenhouse and gas emission has driven the Indonesian government to intensify important and sustainable roles in new and renewable energy as part of maintaining energy autonomy and endurance [3]. In accordance with PP regulation number 79 of 2014 concerning the National Energy Policy, the targetted new and renewable energy combination in 2025 is at least 23% and in 2050 is at least 31%. Indonesia has big potency on new and renewable energy which will be achievable and meet the primary target. Indonesia has a total renewable energy potential equivalent to 442 GW which can be used for electricity generation, whereas the utilization is only 8.8 GW or it is only 0.019% of the total renewable energy in 2018 [2]. The biggest potential for renewable energy may come from solar energy at 207.8 GWp.

To accelerate New and Renewable energy development, the government has established several regulations such as Peraturan Presiden No. 4 in 2016 (Article 14) concerning the Electricity Infrastructure Acceleration prioritizing the use of new and renewable energy Peraturan Menteri ESDM No. 50 in 2017 concerning the Utilization of Renewable Energy Sources as the Supply of Electricity and Peraturan Menteri ESDM No. 49 in 2018 concerning the Use of Rooftop Solar Power Generation System by state-owned corporation Perusahaan Listrik Negara (PLN) customers [4-6]. With the high potential of solar energy in Indonesia and the indorsement from government regulations, this system is expected to be a solution to comply with the high electricity demand in the future by utilizing the solar cell as the source of electrical energy. By considering the growing number of household customers, utilizing the rooftop's consumers as solar power generator base can be an effective and efficient solution. Therefore, the purpose of this research is to analyze the energy produced by rooftop solar power plant system with a household-scale on-grid system with simulation in PVSyst 6.43 software and to analyze the economic feasibility of rooftop solar power plant on grid system household-scale.

2. Material and Methods

2.1. Solar Radiation

Solar radiation is defined as the amount of energy received per unit area and time on earth. The value can be determined depending on such factors, for instance, the location latitude, the season and weather, and the timing. There are two types of radiation which are direct radiation generated from the sun, and indirect radiation generated from atmospheric particles scattering. Indonesia is geographically located on the equator in exact and this resulting in such advantages and great potential of solar energy utilization. Indonesia has a relatively high radiation level which is equal to 4,80 kWh/m2/day [7-9]

2.2. Solar Power Plants

Solar Power Plant is a sunlight-based power plant that uses solar cells to convert the photon sunray radiation into electricity. Solar cells are made from sheer layers of pure silicon and such semiconductor materials. Solar Power Plants is friendly to the environment and it does not produce any noise nor harmful waste to the surroundings. There are several factors that influence the solar cell output power efficiency such as solar radiation, solar cell temperature, solar panel orientation, and shadow leverages [10-12].

2.3. Technical Analysis

The technical analysis is conducted based on the rooftop solar power plant capacity, major components specification utilization and determination, solar panel orientation, and the generated power from the plant. The power generated by rooftop solar power plant is affected by some factors including sunray radiation in the research area, the solar panel slope and its direction, sunlight, temperature, and the technical performance [13]. This technical performance is predicted to decrease in time because of the solar module degradation [14]. The quality of rooftop solar power plant can also be seen by its performance ratio. In general, performance ratio is shown in percentage value that shows the total power produced by the system and also the losses compared while the system is working in STC condition. Solar power plant losses are due to solar panel efficiency, temperature, and inverter efficiency [15, 16].

2.4. Economic Feasibility Analysis

In general, economic analysis can be defined as an economical analysis of technical investment. The purpose of this analysis is to assess the technical investment proposal feasibility by doing an alternative study that is considered the most profitable. Basically, technical investments have a long economic cycle, mostly it has an annual cycle length. On the other hand, the currency values vary time after time. Therefore, the equivalence currency value process is needed [17].

Research on the economic solar cell energy based uses some methods, which are Net Present Value (NPV) and Discounted Payback Period (DPP). Economic research should be conducted due to fairly high expenses in order to find out the optimal and economic result.

2.5. Net Present Value (NPV)

NPV is a method of calculating the net present value. The present assumption is to explain the initial time of the calculation to coincide with when the evaluation was carried out or in the zero year period (0) in the calculation of investment cash flow [18]. Cash

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flow consists of cash in and cash out, Cash flow that only calculated the benefits is called the Present Worth of Benefit (PWB), whereas if cash flow only calculated cost is called the Present Worth of Cosf (PWC). Meanwhile, NPV is obtained from PWB-PWC. To calculate the PWB, PWC, and NPV values, the following equation is used:

$$PWB = \sum_{t=0}^{n} Cb_t (FBP)_t \quad (1)$$

$$PWC = \sum_{t=0}^{n} Cc_t (FBP)_t \quad (2)$$

$$NPV = PWB - PWC \quad (3)$$

Which Cb is Cash flow benefit, Cc is Cash flow cost, FBP is Present Interest Factor, t is Time Period, n is Age of investment. If the NPV value is more than 0, it means that the investment is feasible, whereas if the NPV value is less than 0, it means that the investment is unfeasible [18].

2.6. Benefit Cost Ratio (BCR)

The benefit cost ratio (BCR) method is one of the methods often used in the initial evaluation stages of investment planning or as an additional analysis in order to validate the evaluation results that have been done with other methods. To calculate the value of bcr used equations as follows:

$$BCR = \frac{PWB}{PWC} \quad (4)$$

Where PWB is Present worth Benefit and PWC is Present worth Cost.

To find out if an investment plan is economically viable or not, a specific measure/criterion is required in the BCR method if BCR is more than 1, it means that the investment is feasible. If BCR is less than 1, it means that the investment is unfeasible.

2.7. Payback Period (PP)

Payback period (PP) is the time required to return the investment cost. The way to calculate the PP is to calculate the time needed (years) so that the estimated cumulative cash flow will be the same as the initial investment cost. To calculate the return period used, the calculation is as follows:

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

Where PP is Payback Period, k is Period, CFt is Cash flow period -t.

If the PP time period is shorter than the project life, the project investment will be feasible and if the PP time period is longer than the project life, the project investment is not feasible.

2.8. Internal Rate of Return (IRR)

This Internal Rate of Return (IRR) method looks for interest rates when npv is equal to zero. So, in this IRR method the resulting information relates to the level of cash flow capability in returning the investment described in the form of a period of time. The simple logic explains how much cash flow is capable of returning its capital and how much liabilities it must meet. If the value of the IRR is greater than the interest rate used in the calculation then it can be said to be feasible.

3. Results and Discussion

3.1. Simulation

To stimulate the solar power plant prototype design on PVSyst 6.43, such data are required, for instance, the factors that affect PVSyst 6.43 software simulation result. The factors are including the solar power plant geographic location, solar energy potential data, ambient temperature, solar panel orientation, specifications of the components used, and the daily load estimation. After the simulation process is conducted, the amount of potential electrical energy will be shown. There are numerous values that indicate the amount of produced electrical power, the amount of electricity delivered to the load, and the amount of electric power supplied to the grid. In addition, the solar power plant loss diagram and performance will be shown in graphical data. In this research, a household-scale rooftop solar power plant is designed in Sambiroto Asri Cluster residence number A.9 in Semarang City, Indonesia (**Figure 1,2**).

Figure 1.
Research location in sambiroto asri cluster residence number A9, Semarang City.

Figure 2.
Visualization of the research area located in Sambiroto Asri Cluster Residence, Semarang city.

The research area is located astronomically in 7°1'56.06" South Latitude and 110°27'28.58" East Longitude. According to NASA Prediction of Worldwide Energy Resources data, sun insolation in 2019 in this area is 5,59 kWh/m²/day. Moreover, Semarang city ambient temperature data is collected also. The data mentioned above can be used to generate the result of potential electricity production of a rooftop solar power plant in the research area [19] (**Table 1**).

Table 1.
Monthly insolation and temperature in site location.

Month	Insolation (kWh/m2.day)	Temperature (°C)
January	4,60	27,6
February	5,29	27,9
March	4,55	27,6
April	5,08	28,7
May	5,41	29,0
June	5,14	28,3
July	5,37	27,7
August	5,94	28,0
September	6,49	28,8

October	6,54	29,8
November	6,02	30,1
December	5,30	28,7

According to the real condition in the research area, the planning of the Rooftop Solar Power Plant utilizes a fixed tilted plane with such adjustment to the rooftop condition for about 30° slope and -100° azimuth (**Figure 3**).

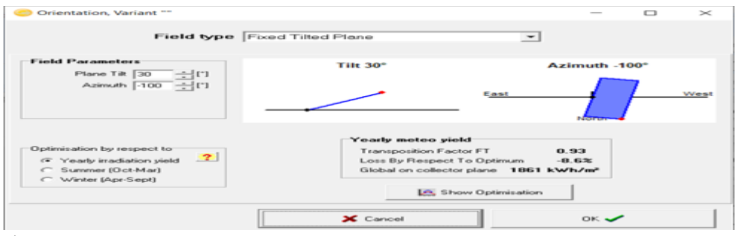

Figure 3.
Solar module orientation.

The major components are solar panels and inverters. Each component consists of two alternative options. Solar Panel alternative option is polycrystalline or monocrystalline solar panel with 405 Wp capacity, while the inverter alternative option chosen for this research is an inverter with more than 97% efficiency. The alternative component options used for Solar Power Plant will be assigned into PVSyst 6.43 software and it will be stimulated in the Rooftop Solar Power Plant planning as explained below (**Table 2-5**).

Table 2.
Solar Panel Specification Variation 1 (Canadian Solar CS3W405P).

Specification	Value
Power Maximum (Pmax)	405 Wp
Open Circuit Voltage (Voc)	47,4 V
Short Circuit Current (Isc)	10,98 A
Maximum Point Voltage (Vmp)	38,9 V
Maximum Point Current (Imp)	10,42 A
Module Efficiency	18,3 %
Dimension (mm x mm x mm)	2108 x 1048 x 40
Price	IDR 3.900.000

Table 3.
Solar panel specification variaton 2 (Risen Solar RSM144-6-405M).

Specification	Value
Power Maximum (Pmax)	405 Wp
Open Circuit Voltage (Voc)	48,75 V
Short Circuit Current (Isc)	10,60 A
Maximum Point Voltage (Vmp)	40,55 V
Maximum Point Current (Imp)	10:00 AM
Module Efficiency	20,2 %
Dimension (mm x mm x mm)	2015 x 996 x 40
Price	IDR 4.400.000

Table 4.
Inverter specification variation 1 (Solax X1-1.1-S).

Specification	Value
Input DC	
Maximum Solar Array Power	1250 W
Maximum DC Voltage	400 V
Maximum Input Current	12:00 AM
MPPT Voltage Range	55-380 V
Output AC	
Maximum Output Power	1100 W
Grid Voltage Range	180-280 V
Maximum Output Current	5,5 A
General Data	
Maximum Efficiency	97,1 %
Dimension	267 x 328 x 116 mm
Price	IDR 6.000.000

Table 5.
Inverter specification variation 2 (Sofar 1,1 kW).

Specification	Value
Input DC	
Maxiumum Solar Array Power	1500 Wp
Maximum DC Voltage	500 V
Maximum Input Current	12:00 AM
MPPT Voltage Range	50-500 V
Output AC	
Maximum Output Power	1100 W
Grid Voltage Range	150-276 V
Maximum Output Current	5,3 A
General Data	
Maximum Efficiency	97,5 %
Dimension	260.5 x 303 x 118 mm
Price	IDR 6.300.000

According to component alternatives above, Rooftop Solar Power Plant that will be stimulated have four different configurations as shown in **Table 6** below.

Table 6.
Solar power plant variation.

Variation	Solar Panel	Inverter	Array Configuration
1	Canadian Solar Polycrystalline		
	405 Wp	Solax X1-1.1-S	3 series of installed modules
	Voc (47,4 V)	Max Vin (400 V)	Voc (142,2 V)
	Isc (10,98 A)	Max Iin (12 A)	Isc (10,98 A)
2	Canadian Solar Polycrystalline		
	405 Wp	Sofar 1100TL-G3	3 series of installed modules.
	Voc (47,4 V)	Max Vin (500 V)	Voc (142,2 V)
	Isc (10,98 A)	Max Iin (12 A)	Isc (10,98 A)
3	Risen Solar Monocrystalline		
	405 Wp	Solax X1-1.1-S	3 series of installed modules.
	Voc (48,75 V)	Max Vin (400 V)	Voc (146,25 V)
	Isc (10,6 A)	Max Iin (12 A)	Isc (10,6)
4	Risen Solar Monocrystalline		
	405 Wp	Sofar 1100TL-G3	3 series of installed modules.
	Voc (48,75 V)	Max Vin (500 V)	Voc (146,25 V)
	Isc (10,6 A)	Max Iin (12 A)	Isc (10,6)

Estimated daily load data in the research area is generated manually and periodically to obtain an exact daily load profile data. The research area has an installed electrical capacity of 1300VA. The following figure will display the daily load profile in the research area (**Figure 4,5**).

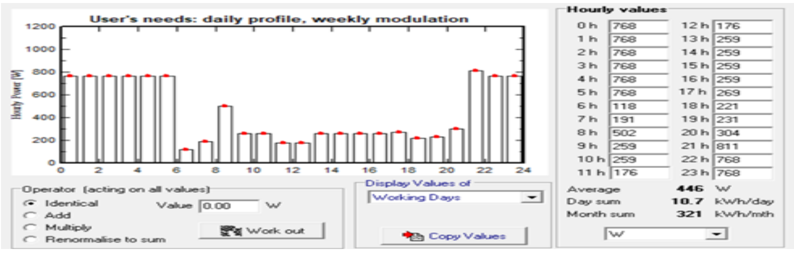

Figure 4.
Daily hourly profile distribution in the research area Working Days.

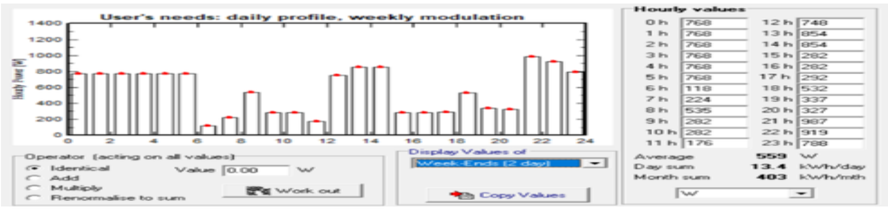

Figure 5.
Daily hourly profile distribution in the research area Week Ends.

The simulation utilizing PVSyst 6.43 software can be conducted after determining and inputting all data.

3.2. Results

The result of PVSyst 6.43 simulation on household-scale rooftop solar power plant planning variations 1, 2, 3, and 4 can be seen in the figures below (**Figures 6-9**).

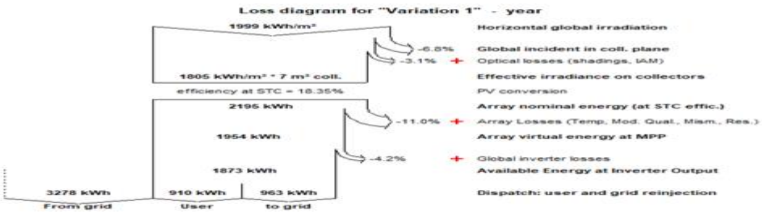

Figure 6.
Variation 1 Results.

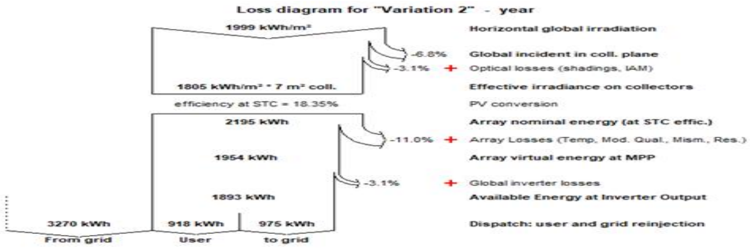

Figure 7.
Variation 2 Results.

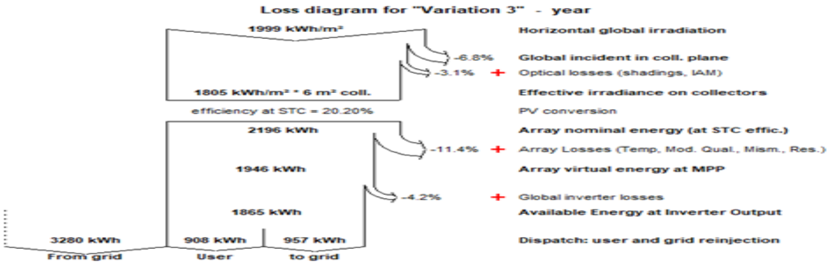

Figure 8.
Variation 3 Results.

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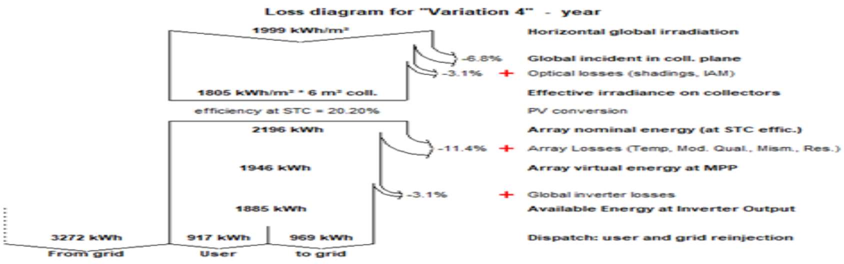

Figure 9.
Variation 2 Results.

3.3. Technical Analysis

Based on the simulation results of PVSyst 6.43 software of each household-scale rooftop solar power plant in the research area, **Table 7** is aimed to show each variations results as follows.

Table 7.
The result of PVSyst 6.43 simulation in Rooftop Solar Power Plant Variation 1, 2, 3, and 4.

Variation	Solar Panel Insulation (kWh/m²)	STC Array Electric Energy (kWh)	Array Output Electric Energy (kWh)	Inverter Output Electric Energy (kWh)	Performance Ratio (%)
Variation 1	1862,1	2195	1954	1873	82,8
Variation 2	1862,1	2195	1954	1893	83,7
Variation 3	1862,1	2196	1946	1865	82,4
Variation 4	1862,1	2196	1946	1885	83,3

It can be concluded from Table 8 that the production sunray array electric energy production in variation 1 and 2 have smaller value in the amount of 2195 KWh per year rather than the variation 3 and 4 which equal to 2196 KWh per year. Thus, it has 1 KWh deviation caused by the solar panel efficiency and surface area used in this research. The variation 1 and 2 utilize Canadian Solar Panel type CS3W405P with an efficiency value of 18.3% and it has surface area of 6,63 m² which produces electrical energy output array of 2195 KWh during STC condition.

On the other hand, the variation 3 and 4 utilize Risen Solar Panel with an efficiency value of 20,2% and it has surface area of 6,02 m2 which produces electrical energy output array of 2196 KWh. Therefore, it can be concluded that the greater solar panel efficiency and the larger solar panel surface area will be resulting in better results. The efficiency is also depending on the type of solar panel. Monocrystalline solar panel types generally have better efficiency because the primary material for making panel which is silicone has greater concentration rather than the polycrystalline type [20].

However, at the same rated power, monocrystalline types have smaller panel surface area than the polycrystalline types. The annual array output for electrical energy in variation 1 and 2 suffered losses from STC conditions of 241 kWh from the STC condition so it becomes 1954 kWh. Moreover, the annual array output for electrical energy in variation 3 and 4 suffered losses from STC conditions of 250 kWh from the STC condition so it results of 1946 kWh. It can be said that these solar panel types have similar losses characteristics for about 9 kWh adrift. If variation 1 and 2 is compared by also looking at the same type of panels, the output electric energy in variation 2 is larger than variation 1. This due to the usage of Sofar Inverter which has efficiency rate of 97.5% in variation 2 is bigger than the usage of Solax inverter X1-1.1-S type which has efficiency rate of 97.1%.

This also can be seen in variation 3 and 4. The output electric energy in variation 4 is larger than variation 2. This due to the usage of Sofar Inverter which has efficiency rate of 97.5% in variation 4 is bigger than the usage of Solax inverter X1-1.1-S type which has efficiency rate of 97.1%. Hence, it could be said that the inverter with a bigger efficiency produces a bigger electrical output as well. It can be concluded that the variation with the biggest performance ratio is variation 2 which has 83.7% ratio, and the smallest performance ratio is variation 3 which has 82,4% ratio.

3.4. Economic Analysis

The feasibility of the rooftop solar power plant that will be designed in the research area will be determined by Net Present Value (NPV) and Benefit Cost Ratio (BCR). While, the best variation will be determined Payback Period (PP) dan Internal Rate of Return (IRR) method. The simulation result is affected by the total investment costs, operational costs, saving costs and electricity sales, discount rates, and inflation values.

The total investment cost of each variation is obtained from surveys to several offline stores in Semarang city and also numerous e-commerce stores in Indonesia, while the discount rate and inflation value are obtained from the official website of Bank Indonesia [21]. The investment costs for each component in the design of a household-scale rooftop solar power plant system variations 1, 2, 3, and 4, can be seen in the **Tables 8-11** below.

Table 8.
Initial investment cost of Rooftop Solar Power Plant Variation 1.

Component	Amount	Unit	Price	Total Price
Canadian Solar Panel	3	Module	IDR 3.900.000	IDR 11.700.000
Solax Inverter	1	Piece	IDR 6.000.000	IDR 6.000.000
Solar Panel Mounting	1	set	IDR 1.107.000	IDR 1.107.000
Solar Panel Grounding	1	set	IDR 360.000	IDR 360.000
Cable	1	set	IDR 420.000	IDR 420.000
Protection	1	set	IDR 643.000	IDR 643.000
Service and others	1	set	IDR 4.990.000	IDR 4.990.000
Total				IDR 25.220.000

Table 9.
Initial investment cost of Rooftop Solar Power Plant Variation 2.

Component	Amount	Unit	Price	Total Price
Canadian Solar Panel	3	Module	IDR 3.900.000	IDR 11.700.000
Solax Inverter	1	Piece	IDR 6.300.000	IDR 6.300.000
Solar Panel Mounting	1	set	IDR 1.107.000	IDR 1.107.000
Solar Panel Grounding	1	set	IDR 360.000	IDR 360.000
Cable	1	set	IDR 420.000	IDR 420.000
Protection	1	set	IDR 643.000	IDR 643.000
Service and others	1	set	IDR 4.990.000	IDR 4.990.000
Total	IDR 25.520.000			

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Table 10.
Initial investment cost of Rooftop Solar Power Plant Variation 3.

Component	Amount	Unit	Price	Total Price
Risen Solar Panel	3	Module	IDR 4.400.000	IDR 13.200.000
Solax Inverter	1	Piece	IDR 6.000.000	IDR 6.000.000
Solar Panel Mounting	1	set	IDR 1.107.000	IDR 1.107.000
Solar Panel Grounding	1	set	IDR 360.000	IDR 360.000
Cable	1	set	IDR 420.000	IDR 420.000
Protection	1	set	IDR 643.000	IDR 643.000
Service and others	1	set	IDR 4.990.000	IDR 4.990.000
Total	IDR 26.720.000			

Table 11.
Initial investment cost of Rooftop Solar Power Plant Variation 4.

Component	Amount	Unit	Price	Total Price
Risen Solar Panel	3	Module	IDR 4.400.000	IDR 13.200.000
Solax Inverter	1	Piece	IDR 6.300.000	IDR 6.300.000
Solar Panel Mounting	1	set	IDR 1.107.000	IDR 1.107.000
Solar Panel Grounding	1	set	IDR 360.000	IDR 360.000
Cable	1	set	IDR 420.000	IDR 420.000
Protection	1	set	IDR 643.000	IDR 643.000
Service and others	1	set	IDR 4.990.000	IDR 4.990.000
Total	IDR 27.020.000			

After the initial investment cost is calculated, then the annual operational and maintenance cost will be estimated. The estimated cost of the Solar Power Plant system will be approximately 1-2% from the total initial investment cost so that the annual operational cost estimation can be seen in tables 12, 13, 14, and 15 below.

Table 12.
Operational Cost of Solar Power Plant system Variation 1.

Component	Amount	Unit	Price	Total Price
O and M Solar Panel	1	Year	IDR117.000	IDR117.000
O and M Inverter	1	Year	IDR60.000	IDR60.000
O and M Solar Panel Mounting	1	Year	IDR11.070	IDR11.070
O and M Solar Panel Grounding	1	Year	IDR3.600	IDR3.600
O and M Cable	1	Year	IDR4.200	IDR4.200
O and M Protection	1	Year	IDR6.430	IDR6.430
Total	IDR202.300			

Table 13.
Operational Cost of Solar Power Plant system Variation 2.

Component	Amount	Unit	Price	Total Price
O and M Solar Panel	1	Year	IDR117.000	IDR117.000
O and M Inverter	1	Year	IDR63.000	IDR63.000
O and M Solar Panel Mounting	1	Year	IDR11.070	IDR11.070
O and M Solar Panel Grounding	1	Year	IDR3.600	IDR3.600
O and M Cable	1	Year	IDR4.200	IDR4.200
O and M Protection	1	Year	IDR6.430	IDR6.430
Total	IDR205.300			

Table 14.
Operational Cost of Solar Power Plant system Variation 3.

Component	Amount	Unit	Price	Total Price
O and M Solar Panel	1	Year	IDR132.000	IDR132.000
O and M Inverter	1	Year	IDR60.000	IDR60.000
O and M Solar Panel Mounting	1	Year	IDR11.070	IDR11.070
O and M Solar Panel Grounding	1	Year	IDR3.600	IDR3.600
O and M Cable	1	Year	IDR4.200	IDR4.200
O and M Protection	1	Year	IDR6.430	IDR6.430
Total	IDR217.300			

Table 15.
Operational Cost of Solar Power Plant system Variation 4.

Component	Amount	Unit	Price	Total Price
O and M Solar Panel	1	Year	IDR132.000	IDR132.000
O and M Inverter	1	Year	IDR63.000	IDR63.000
O and M Solar Panel Mounting	1	Year	IDR11.070	IDR11.070
O and M Solar Panel Grounding	1	Year	IDR3.600	IDR3.600
O and M Cable	1	Year	IDR4.200	IDR4.200
O and M Protection	1	Year	IDR6.430	IDR6.430
Total	IDR220.300			

According to Minister of Energy and Mineral Resources Regulation No. 49 in 2018 article 6, it is stated that the electrical energy from Rooftop Solar Power Plant usage by PLN customers will be calculated based on the export kWh recorded on the export-import kWh meter multiplied by 65% of the applicable electricity tariff.

For the building as the research area is included in the S1 type, the applicable tariff would be IDR 1.467/kWh. Therefore, 65 % of IDR1.467/kWh is IDR 953,55/kWh. This resulting in the estimated annual electricity savings and sales variation that can be seen in tables 16, 17, 18, and 19 as follows.

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Table 16.
Solar Power Plant system Revenue Variation 1.

Component	Amount	Unit	Price	Total Price
Electrical Energy Saving	909,97	Year	IDR 1.467	IDR1.334.926
Electrical Energy Selling	962,7	Year	IDR 953,55	IDR917.983

Table 17.
Solar Power Plant system Revenue Variation 2.

Component	Amount	Unit	Price	Total Price
Electrical Energy Saving	909,97	Year	IDR 1.467	IDR1.347.043
Electrical Energy Selling	962,7	Year	IDR 953,55	IDR929.711

Table 18.
Solar Power Plant system Revenue Variation 3.

Component	Amount	Unit	Price	Total Price
Electrical Energy Saving	909,97	Year	IDR 1.467	IDR1.332.403
Electrical Energy Selling	962,7	Year	IDR 953,55	IDR912.357

Table 19.
Solar Power Plant system Revenue Variation 4.

Component	Amount	Unit	Price	Total Price
Electrical Energy Saving	909,97	Year	IDR 1.467	IDR1.344.579
Electrical Energy Selling	962,7	Year	IDR 953,55	IDR923.895

The implied electrical energy saving is electricity produced from solar panel and it is used separately to supply the home loads needs in accordance with the PVSyst 6.43 software simulation result, whereas the intended electrical energy selling is electricity produced from solar panels and distributed to the grids. By using simulation results, the NPV, BCR, PP, and IRR values for each variation are as follows.

Table 20.
NPV, BCR, PP and IRR value Variation 1, 2, 3 and 4.

Method	Variation 1	Variation 2	Variation 3	Variation 4
NPV	IDR17.289.694	IDR17.421.839	IDR15.309.805	IDR15.439.213
BCR	1,588	1,585	1,49	1,489
Payback Period	10,38	10,39	11,01	11,02
IRR	9,56	9,54	8,81	8,8

According to Table 20, it is shown that NPV value in each variations has more than 0 value dan BCR in each variation has more than 1 value. Therefore, it can be said that the housing-scale rooftop solar power plant investment for each variations are feasible. While the best variation is variation 1 because it has smallest PP value dan biggest IRR value compared to other variations.

4. Conclusions

The solar power plant system designed in this research is connected to the grid. The rooftop solar power plant planning has four different variations which utilizes 3 solar panels with a capacity of 405 Wp and a 1100 W inverter. The electricity produced from this household-scale rooftop solar power plant in the research area is ranging from 1865-1893 kWh with a performance ratio ranging from 82,4-83.7%. Based on the performance ratio result, the most efficient variation is variation 2 with an 83.7% performance ratio value. Each of these planning variations are also economically feasible because it has an NPV value above 0 and BCR value above , while the best variation is variation 1 because it has smallest PP value dan biggest IRR value compared to other variations.

Abbreviations: BCR-Benefit Cost Ratio, IRR-Internal Rate of Return, NPV-Net Present Value and PP-Payback Period.

References

[1] S. N. Kusumaningrum, "The sensitivity of residential electricity demand in Indonesia," *Signifikan: Jurnal Ilmu Ekonomi*, vol. 7, no. 2, pp. 247-266, 2018. https://doi.org/10.15408/sjie.v7i2.6048
[2] S. H. Suharyati and J. L. Pambudi, *Wibowo, and NI Pratiwi.* Jakarta.: Indonesian Energy Outlook, 2019.
[3] P. A. Owusu and S. Asumadu-Sarkodie, "A review of renewable energy sources, sustainability issues and climate change mitigation," *Cogent Engineering*, vol. 3, no. 1, p. 1167990, 2016. https://doi.org/10.1080/23311916.2016.1167990
[4] P. Regulation, "Presidential Regulation of the Republic of Indonesia Number 4 of 2016 concerning the Acceleration of Electricity Infrastructure Development, President of the Republic of Indonesia," 2016.
[5] Regulation of Minister, "Regulation of minister of energy and mineral resource the republic of Indonesia minister of energy and mineral resources the republic of Indonesia," 2017.
[6] Regulation of the Minister, "Regulation of the minister of energy and mineral resources Number 49 of 2018 concerning Use of Rooftop Solar Power Generation Systems by Consumers of PT Perusahaan Listrik Negara (Persero)," pp. 1-18, 2018.
[7] H. Dennis, "The global energy balance in global Physical Climatology," pp. 25-48, 2016.
[8] J. Windarta, A. Nugroho, and B. Bagaskoro, "Design and analysis of technical economics of off-grid systems solar power plant using homer at Cemara Island, Brebes Regency," presented at the In E3S Web of Conferences, EDP Sciences, 2019.
[9] J. Windarta, A. Pratama, and A. Nugroho, "Testing of solar power plant components off-grid systems and engineering economic analysis at Cemara Island, Brebes Regency Indonesia," presented at the In E3S Web of Conferences, EDP Sciences, 2019.
[10] A. Setiawan, S. Kumara, and I. Sukerayasa, "Economic analysis of electricity sales tariff for 1 MWp solar power in Bangli using the life cycle cost method " *Maj Ilm Teknol Elektro*, vol. 13, pp. 27-33, 2014. https://doi.org/10.24843/mite.1502.18
[11] C. Palanichamy and A. Goh, "Solar power for energy sustainability and environmental friendliness of Curtin University Sarawak," presented at the In IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2016.
[12] D. King, W. E. Boyson, and J. Kratochvil, "Experimental optimization of the performance and reliability of stand-alone photovoltaic systems," presented at the Conference Record of the Twenty-Ninth IEEE Photovoltaic Specialists Conference, United States, 2002.
[13] R. J. Mustafa, M. R. Gomaa, M. Al-Dhaifallah, and H. Rezk, "Environmental impacts on the performance of solar photovoltaic systems," *Sustainability*, vol. 12, no. 2, p. 608, 2020. https://doi.org/10.3390/su12020608
[14] D. C. Jordan and S. R. Kurtz, "Photovoltaic degradation rates—an analytical review," *Progress in photovoltaics: Research and Applications*, vol. 21, no. 1, pp. 12-29, 2013. https://doi.org/10.1002/pip.1182
[15] N. H. Reich, B. Mueller, A. Armbruster, W. G. Van Sark, K. Kiefer, and C. Reise, "Performance ratio revisited: Is PR> 90% realistic?," *Progress in Photovoltaics: Research and Applications*, vol. 20, no. 6, pp. 717-726, 2012. https://doi.org/10.1002/pip.1219
[16] Utility-Scale, *Utility-Scale Solar photovoltaic power plants a project developer's guide.* United States, 2015.
[17] Pujawan, *IN and TE Edition.* Yogyakarta: Sea Library, 2019.
[18] M. Giatman and E. Teknik, 3rd ed. Jakarta: PT Raja Grafindo Persada, 2011.
[19] NASA, "NASA prediction of worldwide energy resources," n.d.
[20] A. M. Bagher, M. M. A. Vahid, and M. Mohsen, "Types of solar cells and application," *American Journal of optics and Photonics*, vol. 3, no. 5, pp. 94-113, 2015. https://doi.org/10.11648/j.ajop.20150305.17
[21] Monetary Data Bank Indonesia, "Monetary data bank Indonesia," n.d.