Economic Feasibility Analysis of Rooftop Solar Power Plant Design with Household-Scale On-Grid System in Semarang City

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Abstract. The electricity demand share in the household sector will increase from 49% in 2018 to 58% in 2050 as predicted. This issue is particularly caused by the household growth number which may increase from 67 million in 2018 to approximately 80 million in 2050. For the household customer number are increasing, utilizing rooftop as the base of solar power plants can be an effective and efficient solution. In addition, the government regulation supports the acceleration and development of new and renewable energy. This research aims to analyze the technical economic feasibility of rooftop solar power plant system with a household-scale on-grid system in Semarang City. Through PVSyst 6.43 and RetScreen software also equipped with several primary components, this household-scale rooftop solar power plant investment plan is estimated to have an average revenue return estimated in 10 years later.

Keywords: Solar power plant; On-grid; Technical and Economic Analysis; PVSyst 6.43

1 Introduction

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]. The decrease in fossil energy production especially petroleum and global commitments in reducing greenhouse and gas emission has drove the Indonesian government to intensify important and sustainable roles in new and renewable energy as part of maintaining energy autonomy and endurance. 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 [2], *Peraturan Menteri ESDM No. 50* in 2017 concerning the Utilization of Renewable Energy

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Sources as the Supply of Electricity [3], and *Regulations of the Minister of ESDM No. 49* in 2018 concerning the Use of Rooftop Solar Power Generation System by state-owned corporation *Perusahaan Listrik Negara* (PLN) customers [4]. 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. Solar Power Plant or *Pembangkit Listrik Tenaga Surya* (PLTS) is one of the example of the renewable energy application by taking advantage of the sun as the primary energy source. 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 techno-economic feasibility of rooftop solar power plant system with a household-scale on-grid system by the RetScreen Expert software utilization.

2 Theoretical Background

2.1 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 [5]. 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 [6].

2.2 Technical Economic Analysis

In general, technical 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 [7].

3 Simulation, Result, and Analysis

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, the temperature, the radiation spread, wind speed, solar panel orientation in the spot, 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 by the rooftop solar power plant in the research area. 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.

Fig. 1. Research Location in Sambiroto Asri residence number A9, 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 [8], sun insolation in 2019 in this area is 5,59 kWh/m²/day. Moreover, data generated from NASA Prediction of Worldwide Energy Resources shows the diffuse radiation and wind velocity, also Semarang city temperature data is generated from Semarang-based Station Meteorology, Climatology, and Geophysical Agency. The data mentioned above can be used to generate the result of potential solar energy usage into a rooftop solar power plant in the research area.

Table 1. Insolation, Temperature, Diffuse Radiation, and Wind Velocity in Semarang Location.

Month	Insolation (kWh/m ² .day)	Temperature (°C)	Diffuse Radiation (kWh/m ² .day)	Wind Velocity (m/s)
January	4,60	27,6	2,33	2,59
February	5,29	27,9	2,39	1,42
March	4,55	27,6	2,32	2,06
April	5,08	28,7	2,06	1,76
May	5,41	29,0	1,76	2,65
June	5,14	28,3	1,62	2,82
July	5,37	27,7	1,63	3,04
August	5,94	28,0	1,80	3,11
September	6,49	28,8	2,06	2,99
October	6,54	29,8	2,31	2,75
November	6,02	30,1	2,34	2,37
December	5,30	28,7	2,32	1,42

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° and azimuth 80°.

Fig. 2. Building in the Research Area Located in Sambiroto Asri Cluster Residence, Semarang city.

Fig. 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. Alternative Component Configuration of Rooftop Solar Power Plant

Variation	Solar Panel	Inverter	Array Configuration
1	Canadian Solar Polycrystalline 405 Wp Voc (47,4 V) Isc (10,98 A)	Solax X1-1.1-S Max Vin (400 V) Max Iin (12 A)	3 series of installed modules. Voc (142,2 V) Isc (10,98 A)
2	Canadian Solar Polycrystalline 405 Wp Voc (47,4 V) Isc (10,98 A)	Solis Mini-1000-4G Max Vin (600 V) Max Iin (11 A)	3 series of installed modules. Voc (142,2 V) Isc (10,98 A)
3	Trina Solar Polycrystalline 405 Wp Voc (49,2 V) Isc (10,52 A)	Solax X1-1.1-S Max Vin (400 V) Max Iin (12 A)	3 series of installed modules. Voc (147,6 V) Isc (10,52)
4	Trina Solar Polycrystalline 405 Wp Voc (49,2 V) Isc (10,52 A)	Solis Mini-1000-4G Max Vin (600 V) Max Iin (11 A)	3 series of installed modules. Voc (147,6 V) Isc (10,52)

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 table will display the daily load profile in the research area.

Table 3. Daily Load Profile in the research area

Load	Amount	Power (W)	Time Length (h)	Energy (Wh)
Lamp	10	10	12	1200
TV	1	50	7	350
AC	1	320	13	4160
Refrigerator	1	100	24	2400
Washing Machine	1	300	2	600
Laptop	1	135	12	1260
Handphone	1	5	12	60

According to the Table 3, the daily load profile in the research area will be modified into hourly load profile as follows in Figure 4.

Fig. 4. Daily load profile distribution in the research area.

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

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

Variation	Output of Inverter Electrical Energy (kWh)	Electrical Energy Supplied to the Load (kWh)	Electrical Energy Supplied to the Grid (kWh)
Variation 1	1877	1315	562
Variation 2	1894	1328	566
Variation 3	1881	1315	566
Variation 4	1898	1329	570

After obtaining the electrical energy production from the Rooftop Solar Power Plant in the research area and determining the investment costs for each component in the design of a household-scale rooftop solar power plant system variations 1, 2, 3, and 4, the result can be seen in the tables 5, 6, 7, and 8 below.

Table 5. Initial investment cost of Rooftop Solar Power Plant Variation 1.

Component	Amount	Unit	Price	Total Price
Canadian Solar Panel	3	Module	Rp 3.900.000	Rp 11.700.000
Solax Inverter	1	Piece	Rp 6.000.000	Rp 6.000.000
Solar Panel Cantilaver	1	set	Rp 1.107.000	Rp 1.107.000
Solar Panel Grounding	1	set	Rp 290.000	Rp 290.000
Cable	1	set	Rp 260.000	Rp 260.000
Protection	1	set	Rp 643.000	Rp 643.000
Service and others	1	set	Rp 1.800.000	Rp 1.800.000
Total				Rp 21.800.000

Table 6. Initial investment cost of Rooftop Solar Power Plant Variation 2.

Component	Amount	Unit	Price	Total Price
Canadian Solar Panel	3	Module	Rp 3.900.000	Rp 11.700.000
Solis Inverter	1	Piece	Rp 5.500.000	Rp 5.500.000
Solar Panel Cantilaver	1	set	Rp 1.107.000	Rp 1.107.000
Solar Panel Grounding	1	set	Rp 290.000	Rp 290.000
Cable	1	set	Rp 260.000	Rp 260.000
Protection	1	set	Rp 643.000	Rp 643.000
Service and others	1	set	Rp 1.800.000	Rp 1.800.000
Total				Rp 21.300.000

Table 7. Initial investment cost of Rooftop Solar Power Plant Variation 3.

Component	Amount	Unit	Price	Total Price
Trina Solar Panel	3	Module	Rp 4.000.000	Rp 12.000.000
Solax Inverter	1	Piece	Rp 6.000.000	Rp 6.000.000
Solar Panel Cantilaver	1	set	Rp 1.107.000	Rp 1.107.000
Solar Panel Grounding	1	set	Rp 290.000	Rp 290.000
Cable	1	set	Rp 260.000	Rp 260.000
Protection	1	set	Rp 643.000	Rp 643.000
Service and others	1	set	Rp 1.800.000	Rp 1.800.000
Total				Rp 22.100.000

Table 8. Initial investment cost of Rooftop Solar Power Plant Variation 4.

Component	Amount	Unit	Price	Total Price
Trina Solar Panel	3	Module	Rp 4.000.000	Rp 12.000.000
Solis Inverter	1	Piece	Rp 5.500.000	Rp 5.500.000
Solar Panel Cantilaver	1	set	Rp 1.107.000	Rp 1.107.000
Solar Panel Grounding	1	set	Rp 290.000	Rp 290.000
Cable	1	set	Rp 260.000	Rp 260.000
Protection	1	set	Rp 643.000	Rp 643.000
Service and others	1	set	Rp 1.800.000	Rp 1.800.000
Total				Rp 21.600.000

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 9, 10, 11, and 12 below.

Table 9. Operational Cost of Solar Power Plant system Variation 1.

Component	Amount	Unit	Price	Total Price
O&M Solar Panel	1	Year	Rp117.000	Rp117.000
O&M Inverter	1	Year	Rp60.000	Rp60.000
O&M Solar Panel Cantilaver	1	Year	Rp11.070	Rp11.070
O&M Solar Panel Grounding	1	Year	Rp2.900	Rp2.900
O&M Cable	1	Year	Rp2.600	Rp2.600
O&M Protection	1	Year	Rp6.430	Rp6.430
Total				Rp 200.000

Table 10. Operational Cost of Solar Power Plant system Variation 2.

Component	Amount	Unit	Price	Total Price
O&M Solar Panel	1	Year	Rp117.000	Rp117.000
O&M Inverter	1	Year	Rp55.000	Rp55.000
O&M Solar Panel Cantilaver	1	Year	Rp11.070	Rp11.070
O&M Solar Panel Grounding	1	Year	Rp2.900	Rp2.900
O&M Cable	1	Year	Rp2.600	Rp2.600
O&M Protection	1	Year	Rp6.430	Rp6.430
Total				Rp 195.000

Table 11. Operational Cost of Solar Power Plant system Variation 3.

Component	Amount	Unit	Price	Total Price
O&M Solar Panel	1	Year	Rp120.000	Rp120.000
O&M Inverter	1	Year	Rp60.000	Rp60.000
O&M Solar Panel Cantilaver	1	Year	Rp11.070	Rp11.070
O&M Solar Panel Grounding	1	Year	Rp2.900	Rp2.900
O&M Cable	1	Year	Rp2.600	Rp2.600
O&M Protection	1	Year	Rp6.430	Rp6.430
Total				Rp 203.000

Table 12. Operational Cost of Solar Power Plant system Variation 4.

Component	Amount	Unit	Price	Total Price
O&M Solar Panel	1	Year	Rp120.000	Rp120.000
O&M Inverter	1	Year	Rp55.000	Rp55.000
O&M Solar Panel Cantilaver	1	Year	Rp11.070	Rp11.070
O&M Solar Panel Grounding	1	Year	Rp2.900	Rp2.900
O&M Cable	1	Year	Rp2.600	Rp2.600
O&M Protection	1	Year	Rp6.430	Rp6.430
Total				Rp 198.000

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 Rp 1.467/kWh. Therefore, 65% of Rp1.467/kWh is Rp 953,55/kWh. This resulting in the estimated annual electricity savings and sales variation that can be seen in tables 13, 14, 15, and 16 as follows.

Table 13. Solar Power Plant system Revenue Variation 1.

Component	Amount	Unit	Price	Total Price
Electrical Energy Saving	1.315	Year	Rp 1.467	Rp 1.929.105
Electrical Energy Selling	561,76	Year	Rp 953,55	Rp 535.666

Table 14. Solar Power Plant system Revenue Variation 2.

Component	Amount	Unit	Price	Total Price
Electrical Energy Saving	1.328,3	Year	Rp 1.467	Rp 1.948.616
Electrical Energy Selling	566,12	Year	Rp 953,55	Rp 539.824

Table 15. Solar Power Plant system Revenue Variation 3.

Component	Amount	Unit	Price	Total Price
Electrical Energy Saving	1.315,4	Year	Rp 1.467	Rp 1.929.692
Electrical Energy Selling	565,51	Year	Rp 953,55	Rp 539.242

Table 16. Solar Power Plant system Revenue Variation 4.

Component	Amount	Unit	Price	Total Price
Electrical Energy Saving	1.328,8	Year	Rp 1.467	Rp 1.949.350
Electrical Energy Selling	569,69	Year	Rp 953,55	Rp 548.228

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.

After calculating and inputting all data, the simulation to conduct the technical economic analysis using RetScreen software can be done.

3.2 Result

The result of RetScreen simulation in Rooftop Solar Power Plant planning Variation 1, 2, 3, and 4 can be seen from the figures below.

Kelayakan keuangan		
IRR sebelum pajak - ekuitas	%	12,5%
IRR sebelum pajak - asset	%	12,5%
Pengembalian sederhana	thn	9,6
Balik modal ekuitas	thn	8,4
Nilai Bersih Sekarang (NPV)	IDR	25.149.347
Penghematan siklus hidup tahunan	IDR/thn	1.696.048
Rasio manfaat-biaya (B-C)		2,2
Kemampuan pengembalian hutang		Tanpa hutang
Biaya pengurangan GHG	IDR/tCO ₂	Tanpa pengurangan

Fig. 5. Variation 1 Results

Kelayakan keuangan		
IRR sebelum pajak - ekuitas	%	13%
IRR sebelum pajak - asset	%	13%
Pengembalian sederhana	thn	9,3
Balik modal ekuitas	thn	8,1
Nilai Bersih Sekarang (NPV)	IDR	26.243.654
Penghematan siklus hidup tahunan	IDR/thn	1.769.847
Rasio manfaat-biaya (B-C)		2,2
Kemampuan pengembalian hutang		Tanpa hutang
Biaya pengurangan GHG	IDR/tCO ₂	Tanpa pengurangan

Fig. 6. Variation 2 Results

Kelayakan keuangan		
IRR sebelum pajak - ekuitas	%	12,3%
IRR sebelum pajak - asset	%	12,3%
Pengembalian sederhana	thn	9,8
Balik modal ekuitas	thn	8,5
Nilai Bersih Sekarang (NPV)	IDR	24.873.448
Penghematan siklus hidup tahunan	IDR/thn	1.677.441
Rasio manfaat-biaya (B-C)		2,1
Kemampuan pengembalian hutang		Tanpa hutang
Biaya pengurangan GHG	IDR/tCO ₂	Tanpa pengurangan

Fig. 7. Variation 3 Results

Kelayakan keuangan		
IRR sebelum pajak - ekuitas	%	12,8%
IRR sebelum pajak - asset	%	12,8%
Pengembalian sederhana	thn	9,4
Balik modal ekuitas	thn	8,2
Nilai Bersih Sekarang (NPV)	IDR	25.967.239
Penghematan siklus hidup tahunan	IDR/thn	1.751.205
Rasio manfaat-biaya (B-C)		2,2
Kemampuan pengembalian hutang		Tanpa hutang
Biaya pengurangan GHG	IDR/tCO ₂	Tanpa pengurangan

Fig. 8. Variation 4 Results

3.3 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 Discounted Payback Period (DPP) 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 such 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 [9].

To calculate NPV value, the equation used is as follows.

$$PWB = \sum_{t=0}^n Cb_t(FBP)_t$$
$$PWC = \sum_{t=0}^n Cc_t(FBP)_t$$
$$NPV = PWB - PWC$$

(1)

(2)

(3)

By using these equations and the simulation results, the NPV values for each variation are as follows.

Table 17. NPV value Variation 1, 2, 3 and 4

Variation	NPV
1	Rp 25.149.347
2	Rp 26.243.654
3	Rp 24.873.448
4	Rp 25.967.239

According to Table 17, it is shown that NPV value in each variations has more than 0 value. Therefore, it can be said that the housing-scale rooftop solar power plant investment for each variations are feasible. Berdasarkan tabel 17, terlihat nilai NPV pada masing-masing variasi bernilai lebih dari 0

To calculate DPP value, the equation used is as follows.

$$k_{(DPP)} = \sum_{t=0}^k CF_t(FBP)_t \geq 0 \tag{4}$$

The cumulative cash flow for each variations are described below.

Fig. 9. Cumulative Cash Flow Variation 1.

Fig. 10. Cumulative Cash Flow Variation 2.

Fig. 11. Cumulative Cash Flow Variation 3.

Fig. 12. Cumulative Cash Flow Variation 4.

According to figures 9, 10, 11, and 12, it can be concluded that DPP value can be described by the table below.

Table 18. DPP value Variation 1, 2, 3 and 4

Variation	DPP
1	10,47
2	10,07
3	10,62
4	10,22

Based on the Table 18, the DPP value for each variations are less than 25 years or the projected length cycle. It can be said that the investment on household-scale for each variations are feasible to be applied. Furthermore, it can be concluded that the second variation has the slightest DPP value so this will return the capital rapidly.

4 Conclusion

The solar power plant system designed in this research is a generating system that is connected to the grid (on-grid system). The solar power plant planning is divided into four variations which each of them has its own configuration by using 3x405=1215 Wp of PV and 1000 W inverter. The electricity generated from the household-scale Rooftop Solar Power Plant is ranged from 1877-1898 kWh and each of these planning variations are feasible because it has an NPV value above 0 and also DPP value under the 25 years period. Based on the technical-economic analysis that has been conducted previously, the most feasible investment is namely the second variation, because it has the largest NPV value which is 26.243.658 and the slightest DPP value which is 10,07 years.

References

- [1] S. Suharyati, S. H. Pambudi, J. L. Wibowo, and N. I. Pratiwi, *Outlook Energi Indonesia 2019*. (2019)
- [2] President of the Republic of Indonesia, *Presidential Regulation of the Republic of Indonesia Number 4 of 2016 concerning the Acceleration of Electricity Infrastructure Development*. (2016)
- [3] Minister of Energy and Mineral Resources of the Republic of Indonesia, *Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 50 Year 2017 Concerning Utilization of Renewable Energy Sources for Electric Power Supply*. (2017)
- [4] Minister Of Energy And Mineral Resources Of The Republic of Indonesia, *Regulation of the Minister of Energy and Mineral Resources Number 49 of 2018 Regarding the Use of Roof Solar Power Generation Systems by Consumers of PT. PLN (Persero)*. (2018)
- [5] I. K. Agus Setiawan, I. N. Satya Kumara, and I. W. Sukerayasa, *Performance Analysis Of Solar Electric Power Plant (PLTS) One MWp Interacted In grid In Kayubihi, Bangli*, in Maj. Ilm. Teknol. Elektro, vol. **13**, no. 1, pp. 27–33. (2014)
- [6] D. L. King, W.E. Boyson, and J. Kratochvil, *Analysis of Factors Influencing the Annual Energy Production of Photovoltaic Systems*, in Conference Record of the Twenty-Ninth IEEE Photovoltaic Specialists Conference, pp. 1356–1361 (2002)
- [7] I. N. Pujawan, *Engineering Economics Issue 3*. Yogyakarta: Lautan Pustaka, (2019)
- [8] *NASA Prediction of Worldwide Energy Resources*. [Online]. Available: <https://power.larc.nasa.gov/data-access-viewer/>. [Accessed: 02-Jun-2020]
- [9] *Monetary Data Bank Indonesia*. [Online]. Available: <https://www.bi.go.id/en/moneter/Contents/Default.aspx> . [Accessed: 02-Jun-2020]