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Research Article

Techno-economic Analysis of Rooftop Photovoltaic System (RPVS) using Thin-Frameless Solar Panels for Household Customers in Indonesia

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Abstract: The availability of thin-frameless solar panels on the market today makes the installation of rooftop Photovoltaic (RPVS) systems more attractive. The purpose of this research is to analyze financially the use of thin-frameless solar panels for on-grid RPVS by household electricity customers in Indonesia. The investment cost, the maintenance costs, and the electricity cost savings were involved for the financial analysis, such as Internal Rate of Return (IRR), Net Present Value (NPV), and Pay Back Period (PBP). The calculation is carried out for ideal conditions, the direction of a non-ideal rooftop and the yearly increase of electricity prices is 15 %. The analysis results show that the minimum available rooftop area is still sufficient for the rooftop area needs for solar panel placement, the thin solar panels are safer than standard solar panels, and savings on electricity payments for the return on investment of the RPVS is to be attractive with the IRR > 12 %. The average investment cost of the non-ideal condition is 8 % higher than the ideal condition. This study provides an overview to the policymakers and developers in exploiting the potential of RPVS, especially in Indonesia. For future research directions, this study needs to analyze the technical and economic feasibility of using hybrid smart-grid technology with batteries.

Keywords: Clean Energy, Economic of Solar Energy, Energy Saving, Net Metering, Renewable Energy

1. INTRODUCTION

Indonesia's fossil energy reserves are dwindling due to increasing consumption from year to year. The formation of fossil energy takes millions of years. For this reason, fossil energy consumption must be reduced by utilizing alternative energy sources such as renewable energy. Renewable energy sources can be converted into ready-to-use energy without the greenhouse effect. Renewable energy sources are solar energy, wind energy, water energy, geothermal energy, and biomass energy. As a country located on the equator, Indonesia has abundant solar energy potential [1]. Solar

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energy can be converted into electricity using solar photovoltaic [2] and solar thermal power [3], or into thermal energy with a solar thermal collector [4], or both electricity and thermal with a hybrid photovoltaic and thermal collector [5–7]. Indonesia is targeting renewable energy sources of 23 % by 2025 and 31 % by 2050 in the national energy mix. In 2018, the renewable energy mix only reached 15.2 % with a 3 % contribution from solar energy. This is due to regulatory constraints for installation such as panel weight, rooftop PV aesthetics, as well as operations related to on-grid and off-grid storage systems. Based on customer data from the State-Owned Electricity Company (PLN), the most electricity consumption from 2012 to 2017 was household customers. In this case, the role of the community as a customer is very important. Thus, the use of rooftop PV systems (RPVS) in reducing the electricity consumption of household customers is very relevant to achieving Indonesia's renewable energy mix target [8]. Then, the Minister of Energy and Mineral Resources issued regulations No. 49/2018 and No. 16 /2019, accompanied by a PLN Policy since 2019, making it easier to install RPVS [9]. Thus, the on-grid RPVS becomes more attractive. In addition, PLN also provides regulations and export-import measuring tools for grid-connected, making RPVS for household and commercial buildings more attractive [10].

To utilize the potential of solar energy into electrical energy, the RPVS was developed. This system converts solar energy into electrical energy [11–13]. There are several kinds of solar cell materials, including mono-crystalline (m-si), poly-crystalline (p-si), amorphous-crystalline (a-si), and thin layers of CIS (Cu, Cd, and Zn) [14]. For protection, the surface of the solar panel is covered with glass or plastic. This material must be able to transmit irradiance close to 100 % with low physical weight. In addition, different silicon materials lead to different module efficiency, such as; mono-crystalline 16 %, poly-crystalline 13 %, amorphous-crystalline 8 %, and CIS thin film 10 % [15].

The use of on-grid RPVS in Indonesia by the customers has great potential for achieving the national energy mix target of 23 % by 2025. The simulations for economic analysis were carried out by Subarianto for the implementation of the RPVS by the customers using the Minister of Energy and Mineral Resources regulations No. 49 / 2018 and using import-export kWh and the thick aluminum-framed solar panels [16]. The impact of using the on-grid rooftop PV system in Indonesia has been discussed in both economic and environmental aspects. The environmental aspects are discussed by calculating the reduction of greenhouse gas emissions [17]. The economic aspect was carried out to analyze the cost of a household-scale rooftop PV system [18]. The economic aspect is discussed by calculating the IRR, BEP, Life cycle cost, and benefit-cost ratio [19, 20]. Furthermore, the innovation of solar panel products with the thin-frameless technology. Hopefully, the installation of RPVS will be even more attractive. This innovation does not need to consider additional costs for strengthening the roof truss or changing the existing roof construction. The installation only uses double-adhesive without perforating the roof, to avoid the risk of a leaking roof.

Based on the review above, the financial calculation of the RPVS installation has never been investigated and the relationship between the influence of the usage of RPVS by the household customers with available rooftop area, as well as the technology used that takes into account the weight of solar panels so that they can be installed massively in Indonesia. For this reason, this research aims to analyze financially the usage of thin-frameless solar panels as a prospect for the usage of the rooftop PV system by household electricity customers in Indonesia.

2. MATERIALS AND METHODS

First, conducted survey for the household customers from 450 W to 3 500 W in Jakarta with surrounding cities (Jabodetabek = Jakarta, Bogor, Depok, Tangerang, Bekasi or JMA = Jakarta Metropolitan Area), Bandung, Yogyakarta, Makassar and Pontianak. The survey data taken included the installed power, monthly electricity payments, and the basic electricity price is the basic electricity price that applies from 2019 to June 2020, the number of family members in the house, the size of the house, household electrical equipment used during the day, household electrical equipment used in the afternoon and evening. The electrical power data for household equipment used assumptions as

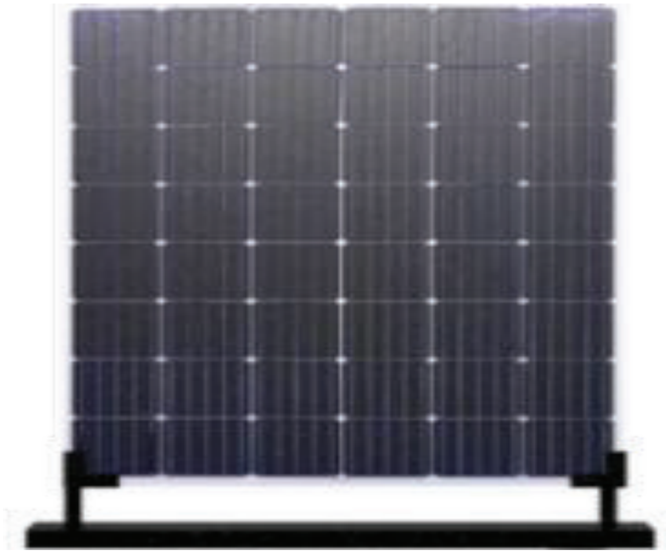


Fig. 1. Thin-frameless solar panel of JLeaf m-si 255 Wp [21]

shown in Table 1.

Another assumption was electricity costs, taken by the average value of payments from all customers per class of the PLN electricity. The upper limit for the RPVS power consumption was 90 % of the installed power according to the board of directors' regulations in 2018. The daily average electricity consumption (DAEC), Ce,day [kWh] can be calculated by Equation (1):

$$C_{e,day} = \frac{B_{e,month}/30}{P_e} \quad (1)$$

where $B_{e,month}$ is the cost of monthly electricity bill [IDR], and P_e [IDR/kWh] is the basic price of electricity.

Second, the capacity of the on-grid RPVS for the household customer's consumptions was calculated. This was to provide an overview of the required rooftop area with the thin-frameless solar panel as shown in Figure 1. As shown in Figure 1(a), the panel is protected with 2.0 mm thin glass without an aluminum frame. Thin glass produces a more perfect irradiance transmission and has a lighter mass [21]. The detailed specification of the thin-frameless solar panels is shown in Table 2 [22].

Third, provided financial analysis on the installation of the on-grid RPVS by the household customers and the potential for saving electricity costs per month using the RPVS. Financial calculation scenarios were carried out using the Internal Rate of Return (IRR) and Pay Back Period (PBP). IRR and PBP from most of the power of the RPVS used up to a maximum of 90 % of the installed power. The investment cost was calculated using components of thin-frameless solar panels with some available power, quality affordable inverters, locally made cables, and other affordable accessories that are but of high quality according to Indonesian national standards as shown in Table 3.

The Inv_{tot} as the total investment can be calculated by Equation (2) and Equation (3):

$$Inv_{tot} = Mat_{tot} + InCom_{tot} \quad (2)$$

$$Mat_{tot} = \sum_{1}^{n} C_n \times P_n \quad (3)$$

where Mat_{tot} [IDR] is the total material cost, C_n is the component item, P_n [IDR] is the price of n component item, and $InCom_{tot}$ [IDR] is the installation and commissioning cost. The total investment costs were divided into Equation (2), namely in ideal conditions and non-ideal conditions. Ideal conditions occur where the direction of the rooftop and the rooftop slope is under the ideal conditions of the solar-energized power plants installation to the angle of incidence of solar rays, hence no additional costs are needed to change and add costs to the rooftop for the installation of the RPVS. Meanwhile, non-ideal conditions occur

Table 1. The electrical power data for household equipment

No	Load items	Power (Watt)
1	Television	100
2	Refrigerator	100
3	Electric stove	400
4	Iron	300
5	Rice cooker	300
6	Water pump	300
7	Fan	75
8	Lamp	50
9	Air conditioning (AC)	350
	Total load (Watt)	1 975

Table 2. Technical specification of JLeaf m-si 255 Wp [22]

Technical specification		
1	Modul type	ST48M255TGP
2	P_{max} (Wp)	255
3	Power tolerance (%)	± 3
4	V_{mp} (V)	27.22
5	I_{mp} (A)	9.39
6	V_{oc} (V)	31.68
7	I_{sc} (A)	10.26
8	Efficiency (%)	19.2
9	Dimension L x W x H (mm)	1 334 x 997 x 3
10	Weight (kg)	7.3
11	Frameless	
12	Screw-free installation	
13	Product warranty	10 yr
14	Power warranty	10 yr ≥ 90 % 25 yr ≥ 80 %

Table 3. Components - Specifications - Cost of the on-grid RPVS of 500 Wp

No	Description	Cost (IDR)	Unit (pcs)	Total Cost (IDR)
1	Solar panels of 255 Wp	1 750 000.00	2	3 500 000.00
2	Jtape adhesive of PV	50 000.00	1	50 000.00
3	Solar Charge Controller	1 300 000.00	1	1 300 000.00
4	Inverter	2 000 000.00	1	2 000 000.00
5	ATS	150 000.00	1	150 000.00
6	MCB AC & DC	100 000.00	2	200 000.00
7	Contactor	200 000.00	2	400 000.00
8	Relay	75 000.00	2	150 000.00
9	Cable protection	100 000.00	1	100 000.00
10	Timer	200 000.00	1	200 000.00
11	Panel box	300 000.00	1	300 000.00
12	Cable and schoen	1 400 000.00	1	1 400 000.00
13	Change exim meter	800 000.00	1	800 000.00
14	Installation cost	500 000.00	1	500 000.00
	Total installation cost			**11 050 000.00**

where the direction of the rooftop and the rooftop slope do not match and cannot generate electricity from solar energy. IRR [%] and PBP [yr] are calculated with Equation (4) and Equation (5) [23]:

$$IRR = I_h + \frac{NPV.I_l}{NPV.I_h - NPV.I_l} x(I_h - I_l) \tag{4}$$

$$PBP = \frac{T_C}{NCF/P} \tag{5}$$

where I_l [%] is the lowest rate, I_h [%] is the highest rate, NPV [IDR] is the Net Present Value, NCF [IDR] is the net cash flow, and P [yr] is the period. If the net positive cash flow is uneven, the following Equation (6) can be used:

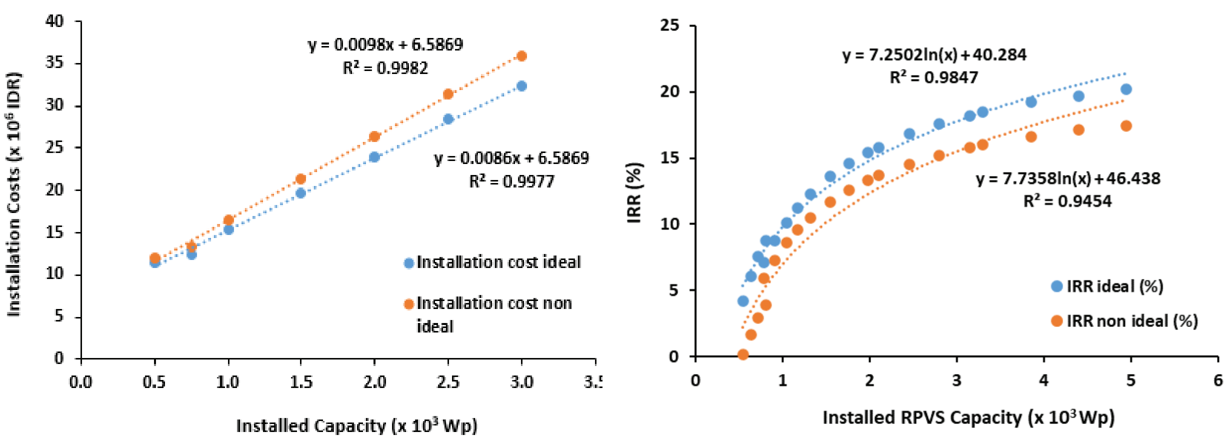
$$PBP = A + \frac{B}{C} \tag{6}$$

where A [years] is the last period number with negative cumulative cash flow, B [IDR] is the absolute value (that is, the value without a negative sign) of the cumulative net cash flows at the end of period A, and C [IDR] is the total cash inflows during the period after period A. The customer monthly electricity costs for households, customer electricity consumption used during the day.

3. RESULTS

The potential for electrical power that may be generated by the RPVS was calculated based on survey results from customers spread over five cities, namely Jabodetabek, Bandung, Yogyakarta, Makassar, and Pontianak as shown in Table 4.

Figure 2 explains the investment value of the RPVS installation for household customers. Figure 2(a) shows the relationship of installation costs with the RPVS installation capacity. The



(a) (b)

Fig. 2. Economic analysis, a). Installation cost (IDR) vs installed capacity (Wp), b). IRR (%) vs installed RPVS capacity (Wp)

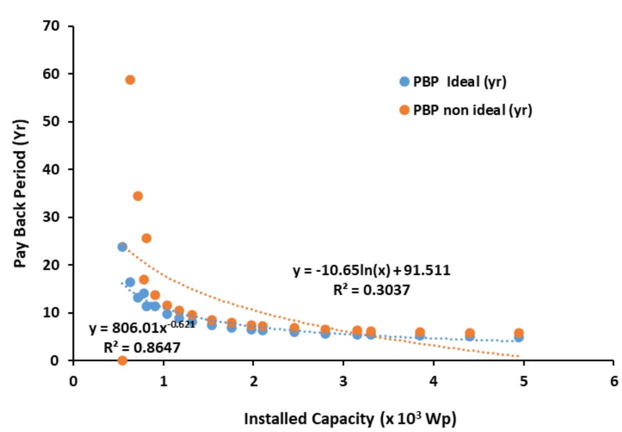


Fig. 3. Relationship between PBP and installation capacity (Wp)

RPVS installation costs follow the equation y = 0.0098x + 6.5869 for ideal rooftop conditions, and y = 0.0086x + 6.5869 for non-ideal rooftop conditions. Attractive investment conditions show that the IRR of ideal conditions was greater than the IRR of non-ideal conditions.

The ideal IRR following the equation, y = 7.2502ln(x) – 40.284. The IRR non-Ideal following the equation y = 7.7358ln(x) – 46.438, where x is the installed RPVS capacity (Wp). Figure 2(b) explains the relationship IRR (%) versus the rooftop solar-energized power plants installation capacity. If an attractive IRR standard was used, the IRR is > 12 %, From the graph, it can be concluded at the point of the rooftop RPVS capacity that attracts the household customers to install it.

Figure 3 shows the PBP versus installed capacity of RPVS. PBP shows the time at which the total value of NPV = 0 (Zero). This means that the NPV of expenditures (investment plus periodic maintenance expenses) was the same as the NPV of income (savings on the electricity payments). The calculation of PBP was used as a benchmark for how long the investment spent will return from the income that comes from saving on electricity payments. The calculation of the PBP was done by calculating the NPV of both investment and savings income. PBP was summed up in the equation, y = 806.01x-0.621 for the ideal condition of the house rooftop. While y = -10.65ln(x) + 91.511 is for the non-ideal conditions.

The average PBP for the installed RPVS capacity was 90 % of the purchasing power. That is for 7.5 yr for ideal rooftop conditions and 11 yr for non-ideal rooftop conditions. The larger the installed RPVS capacity, the smaller the PBP value will be. This means that the investment costs incurred will return in a shorter time as shown in Table 5.

Savings occurred during the day when solar radiation becomes a source of electricity generation from the RPVS. Then, the electrical energy was used for the electrical load of all electrical equipment used during the day. By using a power source from the RPVS, the electricity payment was only to meet the electricity used from the electricity source when the RPVS did not produce electricity (occurs at night if it did not use batteries or when the weather did not allow the RPVS to produce electricity). If viewed from five cities the percentage of electricity cost savings based on installed capacity, all of these cities had considerable savings potential as shown in Figure 4.

The use of the RPVS for household customers caused potential savings in electricity costs. Get the optimum value of savings from the power consumption of the installed RPVS will be determined by regulations and then tested by the financial aspect. The calculation of the savings obtained by assuming the usage of electricity during the day was 30 % of the electricity cost and 90 % of the maximum power.

4. DISCUSSION

Based on the results described above, there are at least three important things that need to be discussed further here. First, related to the installation costs of the RPVS. Under ideal conditions, RPVS has the advantage of not requiring additional costs. This allows RPVS investments to be more attractive to electricity consumers [20]. As shown in Figure 2(a), the investment cost for RPVS installation between ideal and non-ideal conditions had a significant difference to the increase in installation capacity. Therefore, the ideal roof condition can be used as an initial benchmark. This needs to be considered in building a house.

Second, related to PBP as an important indicator in investment. PBP becomes more attractive if its value is less than equal to 10 yr [16]. For non-ideal roof conditions, the minimum installation limit occurred at 1 170 Wp for 1 300 VA customers, as shown in Figure 3 and Table 5.

Third, related to the cost savings of electricity consumption. The most important goal of RPVS installation is to save electricity costs per month [18]. As shown in Figure 4, Jabodetabek had the lowest average savings compared to other cities. This is because the monthly cost of electricity consumption in Jabodetabek was higher than in other cities, which is influenced by the number of household electrical appliances.

The practical application of this study is

Table 4. The PLN household customer survey results data

Region	Installed Power (VA)	Electricity Price (IDR kWh^{-1})	Electricity Cost (IDR mo^{-1})	kWh/ Daytime (Hour 8 to 16)	Afternoon Electric Power (W)
Jabodetabek	900	1 352	283 333	2.10	800
	1 300	1 467	519 565	3.54	1 000
	2 200	1 467	811 628	5.53	1 500
	3 500	1 467	1 807 292	12.32	2 500
Yogyakarta	900	1 352	210 417	1.56	800
	1 300	1 467	310 000	2.11	1 000
	2 200	1 467	650 000	4.43	1 500
	3 500	1 467	1 500 000	10.22	2 500
Bandung	450	1 174	75 000	0.64	350
	900	1 467	181 250	1.24	800
	1 300	1 467	313 889	2.14	1 000
	2 200	1 467	408 333	2.78	1 500
	3 500	1 467	875 000	5.96	2 500
Makassar	450	1 174	150 000	1.28	350
	900	1 467	263 636	1.80	800
	1 300	1 467	228 125	1.56	1 000
	2 200	1 467	681 250	4.64	1 500
Pontianak	900	1 467	285 000	1.94	800
	1 300	1 467	495 000	3.37	1 000
	2 200	1 467	777 778	5.30	1 500
	3 500	1 467	625 000	4.26	2 500

Table 5. The PBP ideal and non-ideal of RPVS capacity is 90 % of the purchasing power

PLN power(VA)	RPVS Capacity (Wp)	Ideal PBP (Year)	Non-ideal PBP (Year)
900	810	11.36	25.64
1 300	1 170	8.93	10.42
2 200	1 980	6.49	7.52
3 500	3 150	5.49	6.33
5 500	4 950	4.95	5.75

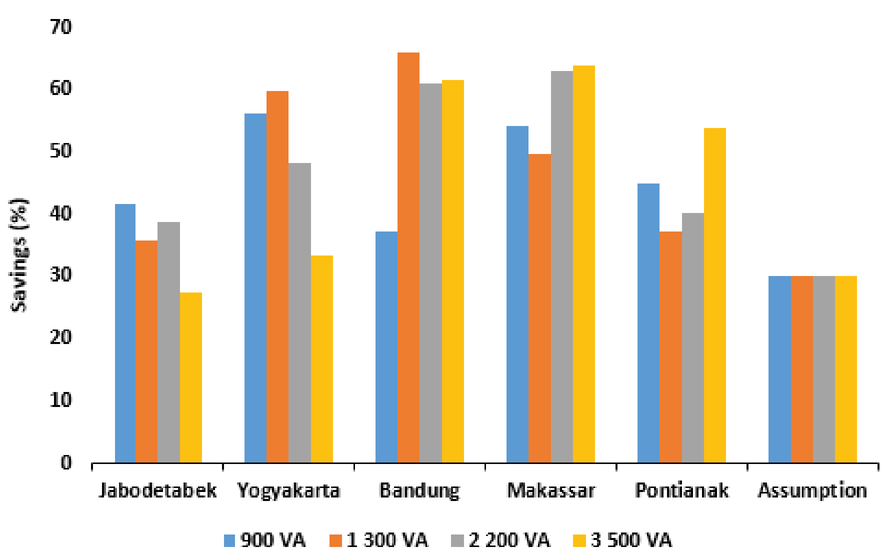


Fig. 4. Monthly electricity cost savings (%)

to provide an overview to policymakers and developers in exploiting the potential of rooftops as an energy producer. This must take into account current and future building standards. In addition, off-grid connected RPVS can also be applied to remote areas [17]. This study contributes to saving electricity costs individually and nationally by utilizing renewable energy sources. The thin-frameless solar panels' technology also reduces installation costs due to minimal modification of the roof construction [22, 23]. In addition, for renewable energy applications in rural areas [24], this type of Thin-frameless PV module can still be used because it is not a hassle in building construction and can reduce installation costs. For future research directions, this study needs to analyze the technical and economic feasibility of using hybrid smart-grid technology with batteries.

5. CONCLUSION

The survey data illustrates the situation of the average electricity consumption in five cities and the monthly costs to pay the electricity to the PLN. The existence of regulations from the Indonesian government is a good step in supporting the usage of renewable energy through the RPVS. The amount of the initial investment of RPVS installation has the potential for substantial savings in monthly financing. In addition, the long service life of the RPVS and the relatively short initial return on investment (PBP) make the RPVS attractive. The RPVS of the household customer that is not ideal affects the economic value of the RPVS investment. The difference in the average investment cost for a non-ideal rooftop has a value of 8 % more expensive than the ideal rooftop. Furthermore, the difference in the average PBP of a non-ideal RPVS has a PBP value of 1 yr longer than the ideal RPVS above 900 Wp of installed capacity.

6. ACKNOWLEDGEMENTS

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7. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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