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Economic Feasibility Investigation of On-Grid and Off-Grid Solar Photovoltaic System Installation in Central Java

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ABSTRACT

Solar energy, as the most abundant renewable energy source, has garnered significant attention for its potential in electricity generation. Photovoltaic (PV) panels, capable of converting solar energy into electricity, have been widely considered for residential applications, including on-grid and off-grid systems. This study seeks to evaluate the economic feasibility of implementing on-grid and off-grid solar PV systems in residential settings through a case study in Gemolong, Sragen. The Hybrid Optimization Model for Electric Renewable (HOMER) software is employed to simulate these systems, providing an economic analysis over a specified time period. Results indicate that the on-grid system presents a more favorable option for the Gemolong region, owing to its optimized monthly production, minimal maintenance costs, and investment potential. The total installation cost for the on-grid system is estimated to be Rp 64,985,200.00, compared to the off-grid system's cost of Rp 745,731,208.82. Furthermore, the on-grid system demonstrates a 13.3% advantage in energy production. Based on the energy and economic analyses, the on-grid PV system is recommended for adoption in the Gemolong area.

1. INTRODUCTION

Renewable energy is pivotal for achieving climate goals and securing a long-term energy supply. Transitioning from a fossil fuel-based energy supply to one with zero carbon emissions is essential for mitigating climate change [1]. Solar energy, a readily available renewable energy source, has yet to be fully harnessed due to factors such as topographical limitations, environmental constraints, and land use restrictions [2]. Solar panels, which can generate electricity and thermal energy, are a promising technology for capitalizing on solar energy and catering to the high energy demands of residential areas [3].

Residential solar systems can be installed as on-grid or off-grid configurations. The on-grid solar system is a method for generating electricity using solar photovoltaics while supplying power to electric utilities [4]. This system comprises components such as a PV module, junction box, inverter, alternating current (AC) disconnect and main panel, net meter, and grid connection [5]. The operational mechanism involves the absorption of light energy by the photovoltaic module, generating electrons and direct current (DC) power [6]. DC power is produced at the output terminals of the PV array and subsequently converted to alternating current (AC) by the inverter. The AC energy can then be utilized directly for electrical loads or fed into the utility grid [7].

Conversely, the off-grid system encompasses components such as a PV panel, maximum power point tracking (MPPT) system, charge controller, battery, and inverter. This system operates by converting solar radiation into electrical energy through the PV panel and directing it to the MPPT for current or voltage regulation. Batteries store surplus electrical energy, while inverters convert DC to AC to match household electricity requirements [8]. Off-grid solar PV systems are typically targeted at impoverished urban communities and rural residents [9].

Analyzing measures to increase average electricity consumption by reducing solar photovoltaic (PV) costs in the residential solar systems market is crucial in the present context [10]. Insight into political, financial, and technical decision analysis is invaluable for informing stakeholders involved in society's transition to clean energy [11]. The HOMER hybrid energy system modeling software is employed in this study to simulate local energy usage at the research center. Sensitivity analysis, one of HOMER's unique features, enables the comparison of the effects of multiple variables [12] and is ideal for examining factors determining cost-effectiveness between off-grid and on-grid systems [13].

This study utilizes the HOMER Pro software to conduct simulations of on-grid and off-grid systems, thereby simulating local energy usage at research centers [14]. The objective is to analyze solar power generation systems proposed for implementation in Gemolong using techno-economic and power comparison methods. By considering the geographical conditions of the region, the on-grid and off-grid solar panel system proposals are evaluated through techno-economic analysis. The potential energy generated serves as a variable to identify the most suitable system for implementation in the area.

2. METHODOLOGY

The HOMER Pro software is employed to analyze and create a model for the suggested energy generation system [15]. Through simulations, it has been discovered that renewable energy sources have the potential to substitute traditional energy sources and offer a practical solution for generating electricity in isolated areas with a reasonable investment [16]. Assessment of city load, air temperature, wind speed, and solar radiation was carried out at an early stage on HOMER Pro. Then, a PV system model is designed, followed by a techno-economic analysis to consider system configuration and settings in HOMER Pro software [17].

The selected area for this study is Gemolong, a sub-district in the city of Sragen, Central Java province, Indonesia. The surrounding region of this sub-district is characterized by hilly terrain and relatively high average temperatures . While the village has access to the local electricity grid, it is unable to reach all areas within the region. Therefore, it is important to explore the beneficial development of solar energy potential in this area. Figure 1 and Figure 2 are illustrations of the system created.

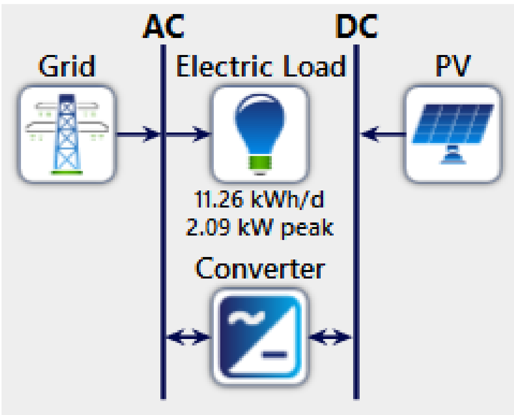

Figure 1. On-grid PV system configuration design

The configured lifespan for the created system is estimated to be 25 years. This time estimate is based on the estimated lifespan of the PV panels used, assuming they are maintained under optimal conditions. The analysis of the projected return on investment is conducted using data provided in HOMER for the Generic Flat PV model. According to the Central Statistics Agency (BPS), Central Java had an inflation rate of 5.22% in March 2023 [18]. In addition, BI had a discount rate of 5.75% in March 2023 [19]. The estimated value given can be seen in Figure 3.

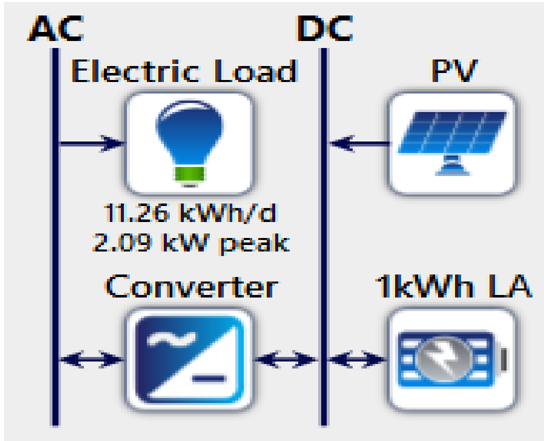

Figure 2. Off-grid PV system configuration design

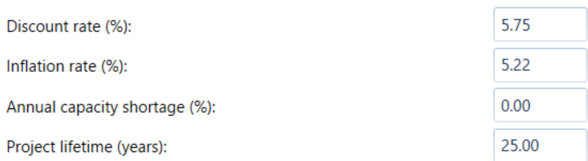

Figure 3. Annual inflation

In general, the PV size must be capable of producing the required peak load demand. However, the size of the PV module depends on several system constraints, including the unmet allowable load and the contribution of the renewable fraction to the system. In grid-connected PV systems, to use the DC current generated by the PV and can be supplied to the load side, an inverter is used to convert the DC current to AC [20]. Technical and economic details of various components for on-grid and off-grid systems are presented in Table 1 and Table 2.

Table 1. On-grid system components [12]

Parameter	PV	Converters
Type	Flat Plate PV	generic
Rate Capacity	1 kW	1 kW
Capital (Rp)	Rp 15,621,635.00/kW	Rp 4,367,652.00/kWh
Replacements (Rp)	Rp 15,621,635.00/kW	Rp 4,367,652.00/kWh
O&M (Rp/year)	Rp 145,588.00/year	0
Life Time	25 years	15 years

Table 2. Off-grid system components [12]

Parameter	PV	Converters	Battery
Type	Flat Plate PV	generic	1 kWh Lead Acid
Rate Capacity	1 kW	1 kW	1 kW
Capital (Rp)	Rp 15,621,635.00/kW	Rp 4,367,652.00/kWh	Rp 4,367,652.00/kWh
Replacements (Rp)	Rp 15,621,635.00/kW	Rp 4,367,652.00/kWh	Rp 4,367,652.00/kWh
O&M (Rp/year)	Rp 145,588.00/year	0	Rp 363,971.00/year
Life Time	25 years	15 years	10 years

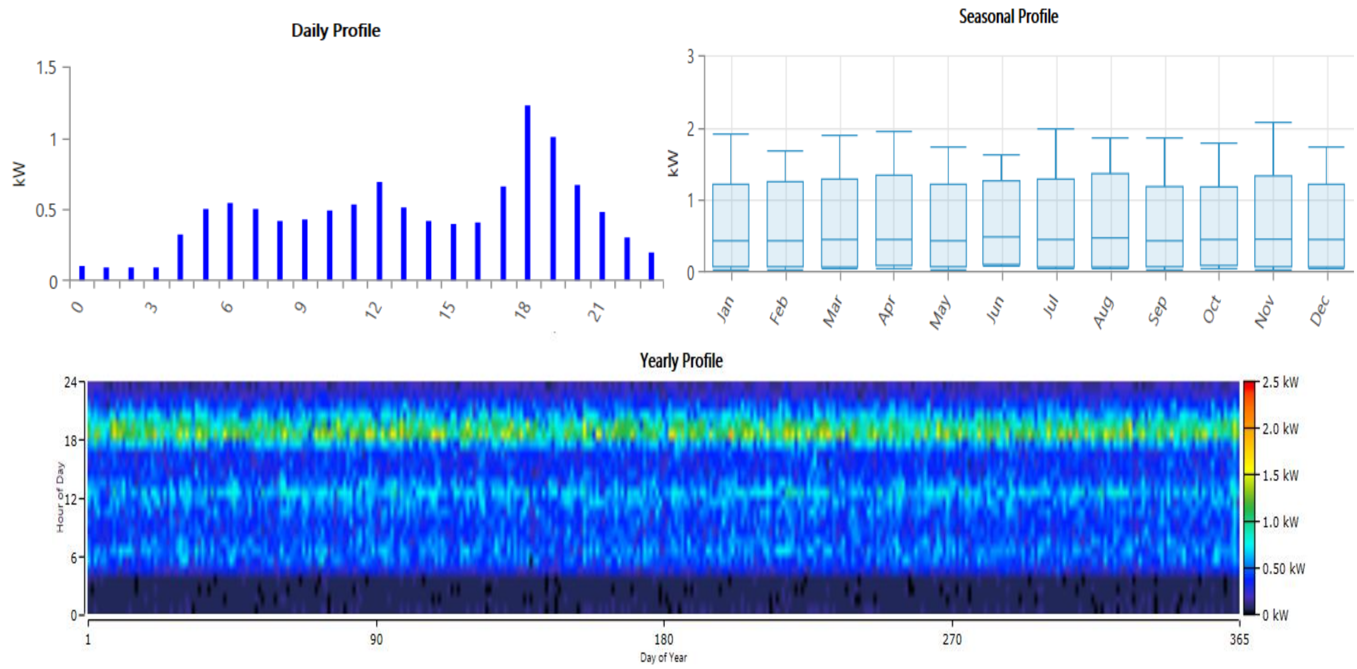

Figure 4. The electrical load on Gemolong

Estimated load profile of electricity consumption for a residential area in Gemolong area, Sragen validated by HOMER. The average consumption load was obtained for the Gemolong area, Sragen, assuming the average usage in Indonesia is 11.26 kWh /d with the maximum power Eban is 2.09 kW [4]. The usage load is calculated every month in detail, as shown in Figure 4. Network input parameters include electricity prices and network selling prices, which are determined by the central government. The price for network electricity for 900 Wh, according to usage in the Gemolong area, Sragen, is Rp 1,500.00, while the selling price is around Rp 911.00 [21].

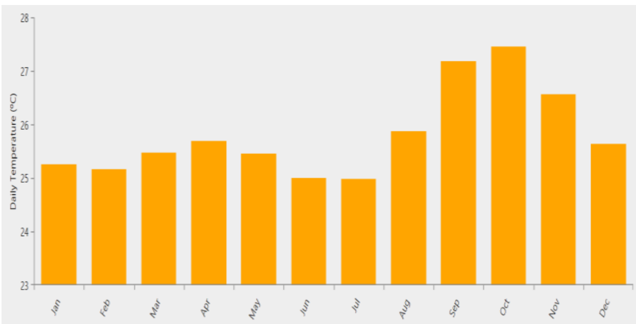

Figure 5. Monthly average temperature

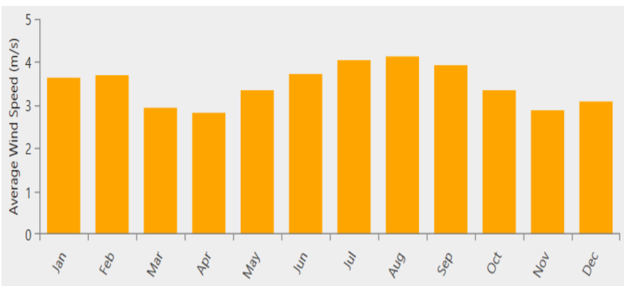

Figure 6. Monthly average wind speed

Figure 7. Monthly average radiation intensity

Data for ambient temperature, wind speed, and solar radiation in Gemolong, Sragen, obtained from NASA Predictions of Worldwide Energy Resources can be obtained from the Resources feature in Design HOMER Pro. This feature presents monthly averages for global radiaton over 22-year period, average wind speed at 50m above the surface of earth over a 30-year period, and average air temperature over 30-year period [22]. Figure 5 shows the average temperature in Gemolong. This sub-district has an annual average temperature of 25.8°C. The highest temperature was in October at 27.46°C, and the lowest was in July at 24.99°C. Figure 6 shows the wind speed at Gemolong. The annual average wind speed is 3.46 m/s. The highest wind speed was in August at 4.12 m/s, and the lowest was in April at 2.81 m/s. Figure 7 shows the average solar irradiance in Gemolong. The annual average solar radiation is 4.80 kWh/m^2/day. The highest irradiation is on September 5.

The simulation results from the HOMER application have an output in the form of economic analysis. The cost of the PV array is determined through the cost of capital owned (Rp), component replacement costs (Rp), and operation & maintenance costs (Rp/yr). The replacement fee is the cost to replace the solar cell if it is damaged up to the warranty period. Economic value plays a vital role in the HOMER simulation process, where the operating process will look for the system configuration with the lowest Net Present Cost

(NPC). HOMER calculates the NPC using the following equation [23]:

$$CNPC=\frac{c_{ann,tot}}{CRF\ .i.Rproj} \quad (1)$$

where,

$c_{ann,tot}$: Total annual fee (Rp/year)
CRF: Capital recovery factor
i: Interest rate
Rproj: Age/service life (years)

The salvage value is the residual value in the HES component. After the project's lifetime was over, this had a significant effect. NPC and was calculated as follows [24]:

$$SC=Cr\frac{L_{rem}}{L_{com}} \quad (2)$$

where,

Cr: Replacement Cost (Rp)
L_{rem}: Remaining life of the component (years)
L_{com}: Component lifetime (year)

Cost of Energy (COE) is the average cost/kWh of usable electrical energy produced by the system. COE is calculated as follows [25]:

$$COE=\frac{c_{ann,tot}}{L_{prim,AC}+L_{prim,DC}} \quad (3)$$

$L_{prim,AC}$ and $L_{prim,DC}$ are the AC and DC loads on the system. Techno-economic analysis is carried out based on several considerations referring to Eq. (1) and Eq. (3). In addition, energy optimization and return analysis are also carried out over a period of 25 years.

3. RESULTS AND DISCUSSION

The installation of on-grid and off-grid systems generally requires the purchase of various components. Off-grid systems usually require a larger initial capital investment compared to on-grid systems. Generally, these two systems have different implementations. The financing of these systems can be divided into component costs, financing costs, and operational parameters, assuming that prices remain stable over the 25-year period. Additionally, the capital investment cost is based on the exchange rate of the Indonesian Rupiah at the time of this research.

3.1 On-grid PV

The on-grid system is connected directly to the power plant used so that it has a smaller initial capital. Table 3 below shows the prices of the on-grid components, and Figure 8 shows the cost flow for on-grid and off-grid systems over the next 25 years, depending on capital, replacement, salvage, operational and fuel values.

Table 3. On-grid system cost flow

Components	Capital (Rp)	Replacement (Rp)	O&M (Rp)	Fuel (Rp)	Salvage (Rp)	Total (Rp)
Generic Flat Plate PV	Rp 187,459,620.00	Rp 0.00	Rp 40,941,601.92	Rp 0.00	Rp 0.00	Rp 228,401,221.92
Grids	Rp 0.00	Rp 0.00	-Rp 222,213,715.91	Rp 0.00	Rp 0.00	-Rp 222,213,715.91
System Converter	Rp 35,996,731.90	Rp 33,383,502.12	Rp 0.00	Rp 0.00	-Rp 10,582,538.43	Rp 58,797,695.59
System	Rp 223,456,351.90	Rp 33,383,502.12	-Rp 181,272,113.99	Rp 0.00	-Rp 10,582,538.43	Rp 64,985,201.60

From the details of NPC costs in Table 3, a total system cost of Rp 64,985,201.60 is obtained, with operational costs per year of -Rp 181,272,113.99. Operational costs indicate a negative value (-) which indicates a surplus of funds from selling electricity to local power plants. For 25 years, this system has been in operation and has a range of financing, as shown in Figure 8.

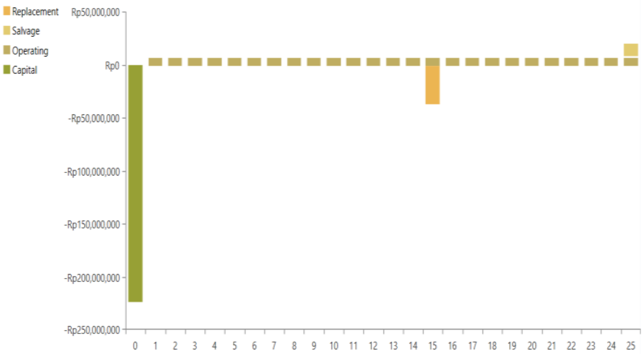

Figure 8. 25-year financing process for on-grid systems

Based on the data shown in Figure 8, in the span of 25 years the system is running, the most significant cost expenditure is in the first year, with enormous capital investment costs. Apart from that, there are some sizable expenditures on component replacement and annual expenses for Operating & Maintenance (O&M) costs. In the on-grid system, the remaining results from the electricity conversion will be sold to local electricity service providers to obtain consistent profits every year. The advantages of implementing an on-grid system can be seen in Table 4 below.

Table 4. System investment project

Project Lifetime	Value
Simple Payback	18.7 yrs
Return on Investment	1.79%
Internal Rate of Return	3.05%
Net Present Value	Rp 79.5M
Investment Capital	Rp 223B
Annualized Savings	Rp 12.9B

In the on-grid system, adding a 1 kW PV already connected to the system can reduce operational costs, too -

Rp 6.76 million/year. Investment in this system is quite adequate, with a return on capital for 18.7 years with an IRR of 3.05%. The system's annual electricity production can be seen in Figure 9 below.

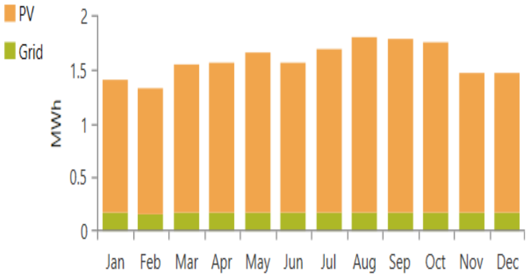

Figure 9. Average monthly electricity production with an on-grid system

The HOMER software can analyze the costs required for this investment. There is also an analysis of the output power of the system. The results of monthly electricity production from this on-grid system are shown in Figure 9. From this figure, the electricity generated from PV panels is influenced by the geographical conditions of the region. At the same time, it tends to be consistent on the grid. The microgrid produces an annual production of 16,942 kWh/yr through the proposed on-grid system.

3.2 Off-grid PV

In contrast to the on-grid PV system, in this off-grid system, the conversion of electrical energy from solar panels will not be connected directly to a local power source. This system does not sell electricity to power plants, so it is only used for personal needs or a particular agency. The problem that arises from this system is that the electrical energy generated by the PV panel, if not used as a whole, must be stored by the system itself. This energy storage process involves other external components in the form of batteries that can effectively store electricity from PV panels. Therefore, the initial investment cost of an off-grid system is usually higher when compared to an on-grid.

Several techno-economic analyzes were also carried out in this off-grid system. More considerable capital is used as a basis for consideration, with no income from the sale of electricity. Large agencies usually implement this system that requires an abundant energy supply, so it is only possible to rely on electricity from power plants in general. The main components of this off-grid system are PV panels, batteries, and power converters, with the total expenditure of each component shown in Table 5.

Table 5. Cost flow off-grid system

Components	Capital (Rp)	Replacement (Rp)	O&M (Rp)	Fuel (Rp)	Salvage (Rp)	Total (Rp)
Generic 1kWh Lead Acid	Rp 109,191,300.00	Rp 301,707,081.14	Rp 213,238,095.89	Rp 0.00	-Rp 93,122,284.72	Rp 531,014,192.30
Generic Flat Plate PV	Rp 162,245,547.94	Rp 0.00	Rp 35,434,791.97	Rp 0.00	Rp 0.00	Rp 197,680,339.91
System Converter	Rp 10,430,080.20	Rp 9,672,894.90	Rp 0.00	Rp 0.00	-Rp 3,066,298.48	Rp 17,036,676.61
System	Rp 281,866,928.13	Rp 311,379,976.04	Rp 248,672,887.86	Rp 0.00	-Rp 96,188,583.21	Rp 745,731,208.82

The details of the total NPC costs in Table 5 show all costs used during this HRES system which were allocated for 25 years. From the details of NPC costs in Table 5, a total system cost of Rp 745,731,200.00 is obtained, with annual operational costs of Rp 248,672,887.86. O&M (Operational and Maintenance) costs every year, PV panels Rp 213,238,095.89/year, and batteries Rp 35,347,79.97/year. It is known that Batteries have higher O&M costs compared to PV panels, thus reiterating that the cost of an off-grid system is more expensive than an on-grid one. PV panels do not require component replacement because they have a lifetime of 25 years according to the proposed project period with a range of financing, as shown in Figure 10.

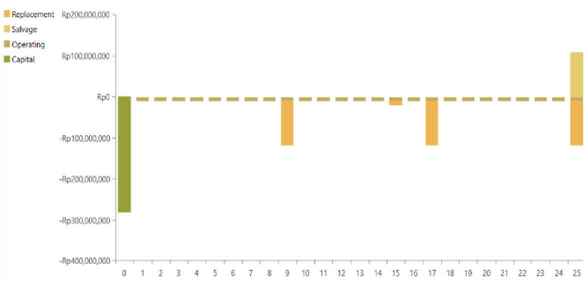

Figure 10. Financing process for 25 years on an off-grid system

Based on the data shown in Figure 10, it can be seen that in the 25 years, the system has been running, the most lavish cost expenditure is in the first year, with significant capital investment costs. Apart from that, there are some sizable expenditures on component replacement and annual expenses for Operating & Maintenance (O&M) costs. The off-grid system does not have a consistent additional profit yearly because it is not sold to electricity service providers. The annual production of this system can be seen in Figure 11 below.

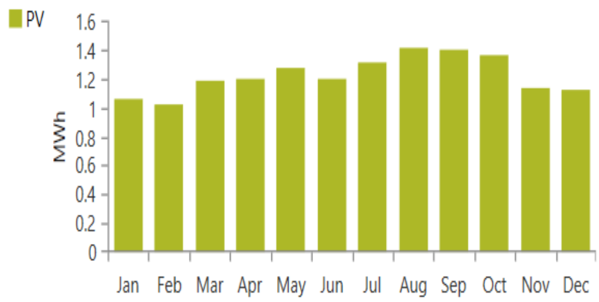

Figure 11. Average monthly electricity production with an off-grid system

The monthly electricity production results from this off-grid system are shown in Figure 11. From the figure, the electricity generated from PV panels is influenced by the geographical conditions of the region. At the same time, it tends to be consistent on the grid. The microgrid produces an annual production of 14.664 kWh/yr. Compared to the on-grid system, this system experienced a decrease in energy production, reaching 13.4%.

The off-grid and on-grid power generation systems show significant results from the simulation results using the HOMER software. The on-grid system is superior to be applied in this area. With only a few maintenance costs required during the 25 years the project is running, the other main components do not require replacement because they have a lifetime and operation hours longer than the project's running time.

4. CONCLUSION

This research compares proposals for solar panel installations with on-grid and off-grid systems in the Gemolong area, Sragen. With the same load, the on-grid system has lower costs compared to the off-grid system. The system cost for on-grid is Rp 64,985,200.00, while the cost for the off-grid system reaches Rp 745,731,208.82. This difference is quite significant because the off-grid system has additional components, namely batteries, which have high investment costs. Additionally, another advantage of the on-grid system is that if the energy generated exceeds household needs, it will be fed back into the electricity grid (PLN) and has the potential for payback. From the proposed on-grid system, payback is achieved after five years of installation. On the other hand, for the off-grid system, excess electricity production beyond household needs will be stored in batteries. When considering the energy generated, the on-grid system is more advantageous with a production difference of 13.3%. Based on these explanations, the on-grid system is more suitable for implementation in the Gemolong sub-district for household purposes. However, for industrial or other purposes, the off-grid system is recommended as it can store a large amount of energy for production needs, considering the unstable electricity supply in this area. This study is expected to help explore the utilization of solar energy in locations that face challenges in accessing electricity.

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REFERENCES

[1] Ahmad, L., Khordehgah, N., Malinauskaite, J., Jouhara, H. (2020). Recent advances and applications of solar photovoltaics and thermal technologies. Energy, 207: 118254. https://doi.org/10.1016/j.energy.2020.118254

[2] Hu, A., Levis, S., Meehl, G.A., Han, W., Washington, W.M., Oleson, K.W., Strand, W.G. (2016). Impact of solar panels on global climate. Nature Climate Change, 6(3): 290-294. https://doi.org/10.1038/nclimate2843

[3] Siraki, A.G., Pillay, P. (2012). Study of optimum tilt angles for solar panels in different latitudes for urban applications. Solar Energy, 86(6): 1920-1928. https://doi.org/10.1016/j.solener.2012.02.030

[4] Arifin, Z., Tjahjana, D.P., Danardono, D., Muqoffa, M., Prasetyo, S.D., Alfaiz, N.F., Sanusi, A. (2022). Grid-connected hybrid PV-wind system simulation in urban Java. Journal Européen des Systèmes Automatisés, 55(4): 477-483. http://dx.doi.org/10.18280/jesa.550406

[5] Kumar, N.M., Kumar, M.R., Rejoice, P.R., Mathew, M. (2017). Performance analysis of 100 kWp grid connected Si-poly photovoltaic system using PVsyst simulation tool. Energy Procedia, 117: 180-189. https://doi.org/10.1016/j.egypro.2017.05.121

[6] Arifin, Z., Suyitno, S., Tjahjana, D.D.D.P., Juwana, W.E., Putra, M.R.A., Prabowo, A.R. (2020). The effect of heat sink properties on solar cell cooling systems. Applied Sciences, 10(21): 7919. https://doi.org/10.3390/app10217919

[7] Kumar, N.M., Subathra, M.P., Moses, J.E. (2018). On-grid solar photovoltaic system: Components, design considerations, and case study. In 2018 4th International Conference on Electrical Energy Systems (ICEES), Chennai, India, IEEE, pp. 616-619. https://doi.org/10.1109/ICEES.2018.8442403

[8] Ghafoor, A., Munir, A. (2015). Design and economics analysis of an off-grid PV system for household electrification. Renewable and Sustainable Energy Reviews, 42: 496-502. https://doi.org/10.1016/j.rser.2014.10.012

[9] Baurzhan, S., Jenkins, G.P. (2016). Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries?. Renewable and Sustainable Energy Reviews, 60: 1405-1418. https://doi.org/10.1016/j.rser.2016.03.016

[10] Asfar, J.A., Atieh, A., Al-Mbaideen, R. (2019). Techno-economic analysis of a microgrid hybrid renewable energy system in Jordan. Journal Européen des Systemes Automatisés, 52(4). https://doi.org/10.18280/jesa.520412

[11] Yuliani, D. (2016). Is feed-in-tariff policy effective for increasing deployment of renewable energy in Indonesia?. The Political Economy of Clean Energy Transitions, 1.

[12] Khalil, L., Bhatti, K.L., Awan, M.A.I., Riaz, M., Khalil, K., Alwaz, N. (2021). Optimization and designing of hybrid power system using HOMER pro. Materials Today: Proceedings, 47: S110-S115. https://doi.org/10.1016/j.matpr.2020.06.054

[13] Kumari, J., Subathra, P., Moses, J.E., Shruthi, D. (2017). Economic analysis of hybrid energy system for rural electrification using HOMER. In 2017 International Conference on Innovations in Electrical, Electronics, Instrumentation and Media Technology (ICEEIMT), Coimbatore, India, IEEE, pp. 151-156. https://doi.org/10.1109/ICIEEIMT.2017.8116824

[14] Sen, R., Bhattacharyya, S.C. (2014). Off-grid electricity generation with renewable energy technologies in India: An application of HOMER. Renewable Energy, 62: 388-398. https://doi.org/10.1016/j.renene.2013.07.028

[15] Hassan, Q., Jaszczur, M., Abdulateef, J. (2016). Optimization of PV/wind/diesel hybrid power system in homer for rural electrification. Journal of Physics: Conference Series. 745(3): 032006. https://doi.org/10.1088/1742-6596/745/3/032006

[16] Swarnkar, N.M., Gidwani, L., Sharma, R. (2016). An application of HOMER Pro in optimization of hybrid energy system for electrification of technical institute. In 2016 International Conference on Energy Efficient Technologies for Sustainability (ICEETS), Nagercoil, India, IEEE, pp. 56-61. https://doi.org/10.1109/ICEETS.2016.7582899

[17] Antonio Barrozo Budes, F., Valencia Ochoa, G., Obregon, L.G., Arango-Manrique, A., Ricardo Núñez Álvarez, J. (2020). Energy, economic, and environmental evaluation of a proposed solar-wind power on-grid system using HOMER Pro®: A case study in Colombia. Energies, 13(7): 1662. https://doi.org/10.3390/en13071662

[18] Badan Pusat Statistik. (2023). https://www.bps.go.id/publication/2023/02/28/18018f9896f09f03580a614b/statistik-indonesia-2023.html.

[19] Bank Indonesia Rate. (2023). https://www.bps.go.id/indicator/13/379/1/bi-rate.html.

[20] Al Garni, H., Awasthi, A. (2017). Techno-economic feasibility analysis of a solar PV grid-connected system with different tracking using HOMER software. In 2017 IEEE International Conference on Smart Energy Grid Engineering (SEGE), Canada, IEEE, pp. 217-222. https://doi.org/10.1109/SEGE.2017.8052801

[21] Apribowo, C.H.B., Ibrahim, M.H., Purnomo, M.R.B. (2020). Design and economic analysis of floating PV-wind turbine plant for renewable energy supply in Indonesia. In AIP Conference Proceedings. 2217: 1.

[22] Panhwar, I., Sahito, A.R., Dursun, S. (2017). Designing off-grid and on-grid renewable energy systems using HOMER Pro Software. Journal of International Environmental Application and Science, 12(4): 270-276.

[23] Türkay, B.E., Telli, A.Y. (2011). Economic analysis of standalone and grid connected hybrid energy systems. Renewable Energy, 36(7): 1931-1943. https://doi.org/10.1016/j.renene.2010.12.007

[24] Aziz, A.S., Tajuddin, M.F.N., Adzman, M.R., Mohammed, M.F., Ramli, M.A. (2020). Feasibility analysis of grid-connected and islanded operation of a solar PV microgrid system: A case study of Iraq. Energy, 191: 116591. https://doi.org/10.1016/j.energy.2019.116591

[25] Rezzouk, H., Mellit, A. (2015). Feasibility study and sensitivity analysis of a stand-alone photovoltaic–diesel–battery hybrid energy system in the north of Algeria. Renewable and Sustainable Energy Reviews, 43: 1134-1150. https://doi.org/10.1016/j.rser.2014.11.103