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Energy Resilience in Remote Areas: A Techno-Economic Study of Off-Grid Solar Power Systems under Highland Microclimate Conditions

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Abstract
In Indonesia's poor, frontier, and remote areas, access to power is still hampered by a lack of network infrastructure and high transportation costs for fossil fuel supply. The techno-economic viability of an off-grid solar power system without a generator set in the vicinity of Nduga Regency is examined in this paper. HOMER Pro software was used for modelling. Local solar radiation potential, daily electricity consumption profiles, battery characteristics, and estimates about maintenance and investment costs were among the input data. The research concentrated on dependability metrics like Loss of Load Probability (LOLP) and indicators like Levelized Cost of Energy (LCOE), Net Present Cost (NPC), and Internal Rate of Return (IRR) in order to identify the best battery SPP configuration. According to simulation studies, solar systems with battery-based energy storage are both economically competitive during the project time and can supply off-grid populations with dependable electricity. However, this design necessitates a substantial initial expenditure due to logistical and topographical challenges. Using off-grid solar power plants without generators is a promising way to increase electrification, improve energy security, and lessen reliance on fuel supply chains, according to the research.

Keywords: Off-Grid Solar Power Plant; Energy Storage System; Techno-Economic Analysis; HOMER Pro.

1. Introduction

1.1. Background

Enhancing social services, fostering economic growth, and raising people's quality of life all depend on having access to energy. However, access to power remains a challenge in Indonesia's underprivileged, frontier, and outermost regions due to physical circumstances, a lacklustre network architecture, and expensive energy distribution logistical costs[1]. At the moment, diesel generators—which are costly to run and emit carbon dioxide—are primarily used in isolated locations. Indonesia possesses a vast amount of solar energy potential, with an average daily radiation intensity of 4 to 5.5 kilowatt-hours per square meter. Off-grid solar power plants with battery-based energy storage devices are one way to supply sustainable energy in places without a grid[2].

1.2. Literature Review

Numerous studies indicate that solar power plants are suitable for usage in remote locations. Rahman et al. (2021), for instance, discovered that hybrid solar power systems using pure diesel can save up to 60% on fuel usage when compared to pure diesel[3]. The potential of hybrid solar power plants in island regions was further examined by Santoso et al. (2022), who discovered that battery integration can increase system reliability despite the comparatively high initial investment costs. However, only hybrid systems with diesel generators are now the subject of research in Indonesia. Because of this, research on off-grid solar power facilities without generators is still restricted to select regions[4].

1.3. Problem Statement

One of Papua's regions, Nduga Regency, has serious issues with restricted access to energy. In addition to fuel and logistics expenses, environmental sustainability concerns also hinder the usage of diesel generators. Therefore, in order to ascertain the technical and financial viability of implementing pure off-grid solar power plants with batteries and to offer a more ecologically friendly electricity option, a thorough study is required[5].

1.4. Objectives

The literature assessment suggests that there is a research gap, specifically a dearth of studies on the use of solar energy producing systems. Off-grid without generator backup in Indonesia, particularly in light of the system's dependability[6]. Thus, the following novelties are presented in this study:

a. Using Nduga Regency as a case study, a techno-economic analysis of off-grid solar power systems that are only battery-based is conducted.
b. Evaluate the feasibility of the system using the Levelized Cost of Energy (LCOE), Net Present Cost (NPC), and Internal Rate of Return (IRR) indicators, as well as the Loss of Load Probability (LOLP) reliability parameter.
c. Suggestions for the best solar power system-battery setup for environmentally friendly electrification in isolated locations.

2. Methods

2.1. Flowchart

The overall methodological framework of this study, as presented in **Figure 1**, outlines the sequence from problem identification, data collection, system design, to techno-economic evaluation using simulation results[7]. Starting from the Start stage, the process continues with problem identification, gathering input data such as solar radiation, load profiles, and battery characteristics, then moves into the System Design stage, which designs the system configuration. After that, simulations were conducted using HOMER Pro software to evaluate the system's performance and economic viability[8]. The simulation results were analyzed based on parameters such as LOLP, LCOE, NPC, and IRR, and then summarized in the final stage as the basis for recommending the best system for sustainable electrification of remote areas[9].

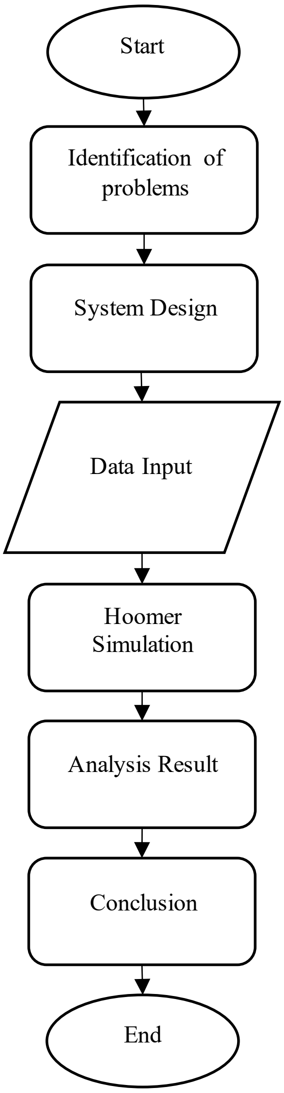

Figure 1. Flowchart Process

2.2. Location of application & Objectivity

The location of the off-grid solar power plant installation is set at coordinates –04.455352°, 138.223135° in the highlands of Papua, Indonesia. The geographical context and site characteristics are depicted in **Figure 2**, showing the installation location in the Nduga highlands with favourable slopes and minimal shading. This region is located at an altitude of approximately 1,200 meters above sea level with an average daily temperature of 18–22°C, resulting in slightly increased solar cell efficiency due to lower heat conditions. The average solar radiation potential reaches 4.8 kWh/m²/day, but cloud distribution and annual rainfall of around 3,000 mm require a panel design that is resistant to high humidity and a drainage system on the support structure. Access to the location via a light dirt road is adequate for component transportation, while low vegetation cover reduces the risk of direct shade on the modules[10].

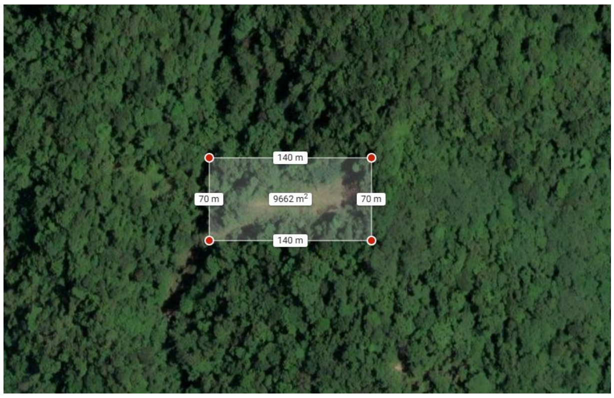

Figure 2. Location of Solar Power Plant Installation

Figure 2 shows the topography based on Google Maps. Land slopes below 7% allow for the installation of panels at an optimal angle (10–15°) without major contouring work. Contour and satellite images also confirm the absence of tall trees in the surrounding area, so that an east-west orientation with little seasonal rotation is sufficient to maximize daily exposure to sunlight. The selection of coordinates—04.455352°, 138.223135°—highlights the advantages of the Papuan highlands: high elevation keeps module temperatures lower, extending cell life while enabling more stable energy output during sunny weather. Conversely, high rainfall and humidity require additional protection for connectors and module support structures to ensure long-term reliability. The complexity of the local climate is a key consideration in material selection, regular maintenance, and adjustments to inverter sizing and battery capacity to cope with power fluctuations[11].

2.3. Description of Power Solar Generation (Off-Grid)

The off-grid solar power system analyzed consists of an inverter, battery bank, and photovoltaic modules without diesel generator support. Variations in solar radiation intensity throughout the day can be observed in **Figure 3**, where the early morning and afternoon fluctuations confirm the influence of local cloud cover. While the battery bank is used to provide backup energy when solar radiation is low, the photovoltaic array is designed to meet daily peak loads based on local consumption profiles. Across the load range, the inverter operates with high efficiency in converting direct current to alternating current[12]. This configuration is modelled as an isolated system that is not connected to the regular power grid.

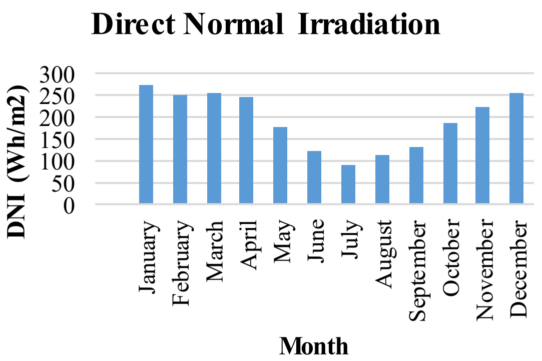

Figure 3. Data Direct Normal Irradiation

With the lowest intensity in the early hours (1–3 a.m.) in the range of 150–300 Wh/m³, the direct solar radiation graph exhibits a steady daily trend. It then rises abruptly towards peak insolation at 6–8 a.m., reaching 900–1,200 Wh/m³, before progressively declining at 9–10 a.m. The highest variations occur in the morning and afternoon hours, which are typically more influenced by local cloud patterns. The midday inter-day variations (days 10 to 18) are smaller, indicating steady sunny weather at coordinates -04.455352°, 138.223135°. In addition to demonstrating the necessity of a sufficient inverter and battery capacity to stabilize the energy supply during early morning and late afternoon fluctuations, this data also validates the significance of the best panel tilt design to optimize radiation capture between 6 and 8 am[13]. The residential load profile shown in **Figure 4** indicates peak energy demand during evening hours, which justifies the sizing of storage capacity to maintain supply reliability.

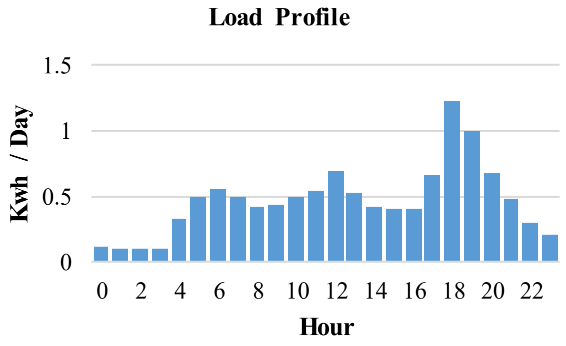

Figure 4. Load Profile Residential

According to the home electrical load profile graph in Nduga Regency, the load is at its lowest between 0 and 5 a.m., when it is less than 0.2 kWh. From 6 to 8 a.m., it gradually increases to 0.6 to 0.8 kWh. After that, the load keeps increasing until it reaches its primary peak at 6:00–7:00 p.m., when it is approximately 1.2–1.3 kWh, and then it starts to progressively decline after 8:00 p.m. The comparatively tiny monthly fluctuations suggest a steady pattern of electricity use all year round.

The main technical specifications and cost composition of each system component are listed in **Table 1**, which forms the foundation for economic analysis and cost modelling. To reliably guarantee the continuity of the household energy supply, this requirement necessitates the construction of an off-grid solar power plant that can maximize production during the day and have enough battery capacity to provide peak loads in the afternoon when solar radiation decreases[14].

Table 1. Component Used

Component	Cost (Rp)	Remark
PV System (1 kW Generic Flat Plate)	90.000.000,00	15 units × 1 kW; Generic model; module efficiency 18%; 25-year warranty
Inverter 15 kW	20.000.000,00	96% efficiency surge protection; 5-year warranty

Battery 15 kWh	45.000.000,00	Configuration 2 × 7.5 kWh; $LiFePO_4$ type; DOD 80%; cycles ≥ 3,000; 5-year warranty

a. Schematic Model

The configuration and power flow of the off-grid PV-battery system are represented in **Figure 5**, modeled in HOMER to simulate energy dispatch and component interactions.

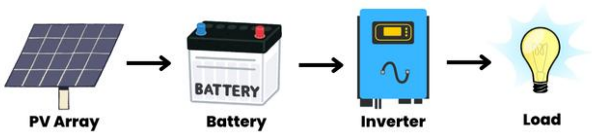

Figure 5. Schematic Model Homer

2.4. Economic Indicator Calculation Methods

a. Net Present Cost (NPC)

NPC is computed as the total of the project's running and maintenance expenses over the course of the project, less the salvage value, all of which are discounted to present value[15]. The general formula:

$$NPC = \sum_{t=0}^{T} \frac{C_{inv,t}+C_{om,t}-S_t}{(1+r)^2} \qquad (1)$$

Where T is the project horizon and r is the annual discount rate.

b. Levelized Cost of Energy (LCOE)

LCOE is obtained from the ratio of NPC to the total energy generated throughout the project period[16]:

$$LCOE = \frac{NPC}{\sum_{t=1}^{T} E_1/(1+r)^t} \qquad (2)$$

where E_t is the annual energy generated after taking into account system losses.

c. Internal Rate of Return (IRR)

IRR is defined as the discount rate *(r^2) that makes the net present value of the project's cash flow equal to zero[17]:*

$$0 = \sum_{t=0}^{T} \frac{C_{int,t}-C_{out,t}}{(1+r^*)^t} \qquad (3)$$

With $C_{int,t}$ and $C_{out,t}$ cash inflows and outflows in year (t)[18].

d. Payback Period

The payback period is the amount of time needed, without discounting, to recoup the initial investment from yearly net cash flow. It is determined by the year that the total cash flow equals the starting investment amount.

3. Results and Discussion

PV modules, lead acid battery storage, and inverters make up the three primary parts of the ideal system produced by the HOMER simulation. HOMER Cycle Charging serves as the dispatch strategy. In order to minimize unmet load in the off-grid environment of Nduga Regency and guarantee a steady supply of energy for the local load profile, this configuration was selected[19].

3.1. PV System Performance and Quality Scheme

Show in **Table 2** examination of off-grid solar power generation performance offers a thorough summary of how environmental factors, design, and maintenance techniques combine to provide a 78% performance ratio (PR). All documented system losses of only 22% are covered by the 18,110 kWh of annual production, or a specific yield of 1,362 kWh/kWp. Because of Papua's high altitude (18–22 °C on average), the working temperature of the modules, which accounts for the majority of losses (8%), stays low, minimizing efficiency losses brought on by temperature changes. Oversized DC wire lowers resistive losses to 4%, whereas inverter losses of 4% represent the 2.72 kW inverter's 96% efficiency[20].

In the installation design, inter-module mismatch (3%) and soiling (3%) problems were also expected. Monthly cleaning maintenance decreased dust accumulation that could lower panel output, and the parallel connection and module string design were adjusted to limit current variations between modules. Based on solar elevation angle calculations at latitude -04.455352°, the 180° south-facing module orientation and 12° tilt were chosen to ensure optimal sunlight penetration all year round without requiring major terrain change[21].

System performance indicators, including efficiency, yield, and total losses, are summarized in **Table 2**, highlighting the relatively high-performance ratio achieved under highland climatic conditions.

In techno-economic analysis, limiting total losses at this low level lowers the Levelized Cost of Energy (LCOE) and Net Present Cost (NPC) while simultaneously increasing energy yield. The information in Table 2 is used to determine the cost per kWh and is fed into the HOMER model to assess the investment's viability. The off-grid solar power system in the highlands of Papua is dependable and cost-effective due to a combination of advanced technical design, favourable environmental conditions, and preventative maintenance techniques.

Table 2. Summary of Performance and Losses of Off-Grid PV Systems.

Parameters	Value	Description
Installed capacity	13,3 kW	PV Generic Flat Plate
Annual production	18.110 kWh	Annual total output
Specific Yield	1.362 kWh/kWp-year	Production of each kWp value
Performance Ratio	78 %	Comparison of actual and theoretical ratios
Total Losses	22 %	Total losses
Inverter	4 %	Inverter efficiency 96%
DC Wiring	4 %	Resistive cable loss
Temperature	8 %	Module temperature loss (18–22 °C)
Mismatch	3 %	Inter-module variation
Soiling	3 %	Losses due to dust; monthly cleaning

3.2. Electricity Production and Consumption in Solar Power Systems

According to the simulation results, an off-grid solar power system with a 13.3 kW PV capacity may produce 18,110 kWh of energy annually, all of which will come from renewable energy sources (Renewable Fraction = 1.000). The principal AC load uses 4,107 kWh of energy annually; there is neither a DC load nor a deferrable load, so the AC load is the only source of system consumption[22]. As shown in **Figure 6**, the monthly PV production remains relatively constant throughout the year, supporting the system's capability to ensure energy resilience despite climatic variations. There is room for system optimization by adding productive loads or integrating a more effective storage system, as the large gap between production and consumption results in 13,265 kWh of extra electricity annually, or 73.2%. Because of the extremely low unmet load (2.17 kWh/year, or 0.0528%) and the low capacity (3.92%), the system can reliably supply energy demands.

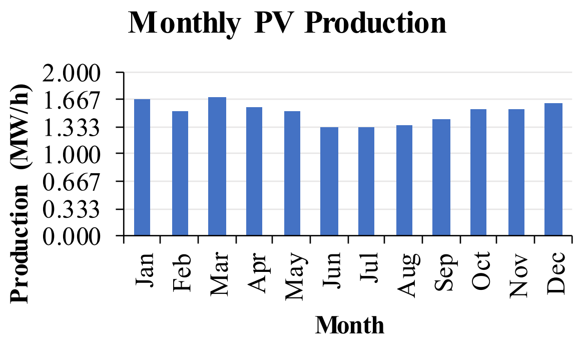

Figure 6. Monthly PV Production

The solar power system's energy production is distributed consistently throughout the year, with a comparatively constant monthly output of about 1.5 MWh. The system can meet daily energy needs without experiencing severe variations because of its constancy, which matches the stability of solar radiation in Papua New Guinea's highlands. Planning energy storage capacity, especially to guarantee supply during afternoon and evening peak loads, depends heavily on this production stability. The overall annual energy balance between production, consumption, and losses is detailed in **Table 3**, which serves as the primary dataset for calculating economic indicators such as LCOE and NPC.

To fully assess technical efficiency and investment feasibility in the context of techno-economic analysis, annual production and consumption data, excess electricity, unmet load, capacity shortage, and renewable fraction values must be directly connected to system costs like Levelized Cost of Energy (LCOE) and Net Present Cost (NPC)[23].

Table 3. Performance and Losses of Off – Grid PV Systems.

Category	Component / Value	Description
Energy Production	18.110 kWh/year	100% comes from PV Generic Flat Plate

Energy Consumption	4.107 kWh/year	Primary AC Load
	0 kWh/year	Primary DC Load
	0 kWh/year	Deferrable Load
Excess Electricity	13.265 kWh/year	73.2% of total production unused
Unmet Load	2,17 kWh/year	0.0528% of total demand unmet
Capacity Shortage	3,92%	System capacity shortage relative to load
Renewable Fraction	1.000	System fully uses renewable energy
Max. Renewable Penetration	4.967%	Maximum penetration of renewable energy relative to load

3.3.Economic Analysis

The economic projection summarized in **Figure 7** illustrates the cumulative cash flow over 25 years, serving as the basis for calculating payback period and investment feasibility. The total net present cost (NPC) of the off-grid solar power system is recorded at Rp158,316,960, the levelized cost of energy (LCOE) at Rp2,981.90/kWh, and the annual operating cost at Rp309,552.20. Using the local electricity tariff in accordance with the Minister of Energy and Mineral Resources Regulation (Rp1,467/kWh), the estimated payback period for the system—based on electricity cost savings from the primary AC load (4,107 kWh/year)—is approximately 25 years[24].

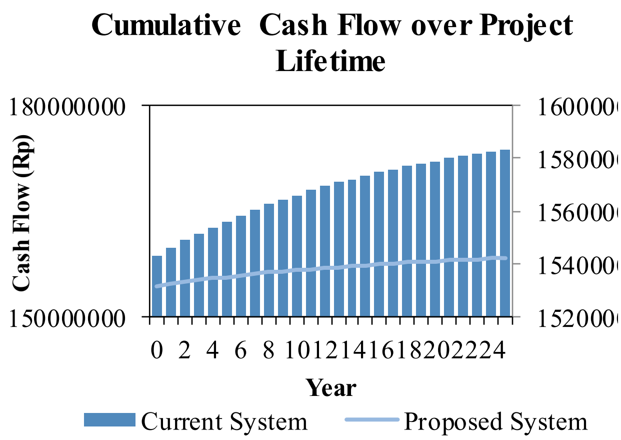

Figure 7. Cash flow in 25 years

A scenario of 0.8% module degradation per year with inverter replacement in the 15th year raises the NPC to IDR 174 million and the LCOE to IDR 3,150/kWh. Key financial parameters including Net Present Cost, Levelized Cost of Energy, and Payback Period are presented in **Table 4**, providing a concise overview of the system's techno-economic viability.

Sensitivity analysis ±20% on capital costs reveals that NPC can vary between IDR 126–190 million and LCOE in the range of IDR 2,400–3,600/kWh. An overview of the range of long-term investment risk and financial viability is given by this method.

Table 4. Summary of Economic Indicators

Parameters	Value	Description
Net Present Cost (NPC)	Rp158.316.960	Total capitalized costs
Levelized Cost of Energy (LCOE)	Rp2.981,90/kWh	Average energy production costs
Operating Cost	Rp309.552,20/year	Annual O&M costs
Local Electricity Rates	Rp1.467/kWh	In accordance with ESDM Regulation
Payback Period	26 years	NPC ÷ (load × tariff)
NPC Sensitivity	Rp126–190 million	±20% capital costs
LCOE sensitivity	Rp2.400–3.600/kWh	±20% capital costs
Relegation Scenario	NPC Rp174 Million; LCOE Rp3.150/kWh	Module degradation 0.8%/year; inverter replaced in the 15th year

3.4. Sensitivity Analysis

The impact of changes in capital costs (±20%), extra installation costs (10%), transportation costs (8% of capital costs, given Papua New Guinea's mountainous terrain), and module degradation scenarios (0.8%/year) with inverter replacement in the 15th year are all considered in sensitivity analysis. Sensitivity results in **Table 5** demonstrate how variations in capital, installation, and transportation costs significantly affect the NPC and LCOE, revealing potential investment risks in remote locations. The addition of installation and transportation expenses greatly increases the NPC and LCOE, while fluctuations in capital costs and module degradation create a range of long-term investment risks.

Table 5. NPC and LCOE Sensitivity Analysis Results.

Scenario	NPC (Rp Million)	LCOE (Rp/kWh)
Based Case	158,3	2.981,9
Capital Cost – 20%	126,6	2.385,5
Capital Cost + 20%	190,0	3.578,3
Installation Cost (+ 10% Cap. Cost)	174,1	3.278,1
Transportation Cost (+ 8% Cap. Cost)	170,6	3.211,4
Installation + Transportation (+ 18% Cap. Cost)	186,9	3.545,2
Module Degradation 0.8% & Inverter Replacement in Year 15	174,0	3.150,0

3.5.Discussion

According to the simulation results, the 13.3 kW off-grid solar power generation in Nduga Regency may achieve an NPC of Rp158 million and an LCOE of Rp2,982/kWh, which is less than the local PLN price. This data shows that both are economically competitive. High reliability is shown by the low unmet demand (0.05%) and capacity shortage (3.9%), while the 73% extra power creates room for more productive load application or storage optimization.

Logistics planning and the use of local components are essential since sensitivity analysis reveals that installation and shipping expenses in Papua's rugged terrain can raise the NPC to IDR 187 million and the LCOE to IDR 3,545/kWh. The need to employ high-quality modules and proactive maintenance plans is strengthened by the fact that module degradation of 0.8% each year and inverter replacement in the fifteenth year add up to 10% in additional expenditures.

All things considered, this system is both technically and financially feasible for use in remote locations thanks to the combination of established technological design, conducive environmental conditions, and cost-reduction techniques. To enhance long-term investment suggestions, a thorough dynamic load analysis and component price sensitivity study should be carried out for more research.

4. Conclusion

The case study in Nduga Regency demonstrates that a 13.3 kW off-grid solar system with battery storage can produce 18,110 kWh/year (specific yield 1,362 kWh/kWp) with a performance ratio of 78% and a 100% renewable fraction, meeting an annual primary AC demand of 4,107 kWh with negligible unmet load while yielding a large surplus (73.2%). Economically, the system shows an NPC of approximately IDR 158.3 million and an LCOE of about IDR 2,982/kWh, lower than the local PLN tariff, yet results are highly sensitive to increases in capital, installation, and transportation costs, which can raise NPC and LCOE substantially. Overall, the solution is technically and financially viable for rural electrification provided careful logistical planning, quality components, preventive maintenance, battery capacity optimization, productive load integration, and long-term field validation[25].

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References

[1] I. Sulaeman *et al.*, “Remote Microgrids for Energy Access in Indonesia—Part I: Scaling and Sustainability Challenges and A Technology Outlook,” *Energies (Basel)*, vol. 14, no. 20, p. 6643, Oct. 2021, doi: 10.3390/en14206643.

[2] Rinaldi Maulana, “Pra-studi Kelayakan Sistem Hibrida PV-Baterai-PLTD di Daerah Pedesaan Wilayah Maluku,” *Elposys: Jurnal Sistem Kelistrikan*, vol. 11, no. 2, pp. 92–97, Jun. 2024, doi: 10.33795/elposys.v11i2.5165.

[3] J. Y. Koffi, K. M. Sako, B. K. Koua, P. M. E. Koffi, Y. Nguessan, and A. K. Diango, "Study and Optimization of a Hybrid Power Generation System to Power Kalakala, a Remote Locality in Northern Côte d'Ivoire," *International Journal of Renewable Energy Development*, vol. 11, no. 1, pp. 183–192, Feb. 2022, doi: 10.14710/ijred.2022.38492.

[4] D. Sahidin, B. Ihsan, T. D. Rachmildha, and D. Hamdani, "Perancangan dan Pemodelan PLTS Off-Grid dengan Penyimpanan Energi Hibrida Berbasis Superkapasitor-Baterai: Studi Kasus di Desa Karamina, Papua," *Jurnal Riset Rekayasa Elektro*, vol. 7, no. 1, pp. 23–34, Jun. 2025, doi: 10.30595/jrre.v7i1.26325.

[5] A. Saputra, A. Setyawan, Chairiman, A. I. Putri, and L. J. Diguna, "Techno-economic analysis of hybrid PV-Battery-diesel system for isolated Dockyard In West Papua," *E3S Web of Conferences*, vol. 475, p. 03008, Jan. 2024, doi: 10.1051/e3sconf/202447503008.

[6] N. A. Pambudi *et al.*, "Renewable Energy in Indonesia: Current Status, Potential, and Future Development," *Sustainability*, vol. 15, no. 3, p. 2342, Jan. 2023, doi: 10.3390/su15032342.

[7] L. Subekti, C. F. Nugraha, M. Arrofiq, A. A. Muthahhari, B. E. Prasetyo, and Q. A'yun, "Techno-Economic Analysis for Raja Ampat Off-Grid System," *Jurnal Nasional Teknik Elektro*, pp. 42–50, Mar. 2024, doi: 10.25077/jnte.v13n1.1180.2024.

[8] T. M. I. Riayatsyah, T. A. Geumpana, I. M. R. Fattah, and T. M. I. Mahlia, "Techno-Economic Analysis of Hybrid Diesel Generators and Renewable Energy for a Remote Island in the Indian Ocean Using HOMER Pro," *Sustainability*, vol. 14, no. 16, p. 9846, Aug. 2022, doi: 10.3390/su14169846.

[9] A. Mansur, "Hybrid Electrical System Optimization of Remote Island using HOMER," *INTEK: Jurnal Penelitian*, vol. 8, no. 2, pp. 108–113, Oct. 2021, doi: 10.31963/intek.v8i2.2962.

[10] I. Mcingani, E. L. Meyer, and O. K. Overen, "The Impact of Ambient Weather Conditions and Energy Usage Patterns on the Performance of a Domestic Off-Grid Photovoltaic System," *Energies (Basel)*, vol. 17, no. 19, p. 5013, Oct. 2024, doi: 10.3390/en17195013.

[11] D. Avithi Desappan, E. Natarajan, and L. Ponnusamy, "Performance Evaluation of Photovoltaic System in Humid Atmosphere," *Applied Mechanics and Materials*, vol. 787, pp. 57–61, Aug. 2015, doi: 10.4028/www.scientific.net/AMM.787.57.

[12] T. Khatib and D. H. Muhsen, "Optimal Sizing of Standalone Photovoltaic System Using Improved Performance Model and Optimization Algorithm," *Sustainability*, vol. 12, no. 6, p. 2233, Mar. 2020, doi: 10.3390/su12062233.

[13] S. Attique *et al.*, "An overview of the pressure- and strain-induced changes in the structural and optoelectronic properties of organometal halide perovskites," *Solar Energy*, vol. 239, pp. 198–220, Jun. 2022, doi: 10.1016/j.solener.2022.05.009.

[14] A. Kallert, R. Egelkamp, U. Bader, D. Münnich, L. Staudacher, and H. Doderer, "A multivalent supply concept: 4th Generation District Heating in Moosburg an der Isar," *Energy Reports*, vol. 7, pp. 110–118, Oct. 2021, doi: 10.1016/j.egyr.2021.09.032.

[15] N. Matera, D. Mazzeo, C. Baglivo, and P. M. Congedo, "Hourly forecasting of the photovoltaic electricity at any latitude using a network of artificial neural networks," *Sustainable Energy Technologies and Assessments*, vol. 57, p. 103197, Jun. 2023, doi: 10.1016/j.seta.2023.103197.

[16] A. C. Y. Acevedo Arenas, Y. A. Muñoz Maldonado, J. F. Petit Suárez, D. H. Morales Sánchez, and D. F. Ramírez Contreras, "Towardsa Standardized LCOE Calculation for Informed Decision-Making in Energy Policy and Investment: Application to the Colombian Context," *International Journal of Energy Economics and Policy*, vol. 14, no. 6, pp. 523–541, Nov. 2024, doi: 10.32479/ijeep.16280.

[17] V. Delapedra-Silva, P. Ferreira, J. Cunha, and H. Kimura, "Methods for Financial Assessment of Renewable Energy Projects: A Review," *Processes*, vol. 10, no. 2, p. 184, Jan. 2022, doi: 10.3390/pr10020184.

[18] E. B. Agyekum and C. Nutakor, "Feasibility study and economic analysis of stand-alone hybrid energy system for southern Ghana," *Sustainable Energy Technologies and Assessments*, vol. 39, p. 100695, Jun. 2020, doi: 10.1016/j.seta.2020.100695.

[19] M. Ramesh and R. P. Saini, "Dispatch strategies based performance analysis of a hybrid renewable energy system for a remote rural area in India," *J Clean Prod*, vol. 259, p. 120697, Jun. 2020, doi: 10.1016/j.jclepro.2020.120697.

[20] L. Phuong Truong, H. An Quoc, H.-L. Tsai, and D. Van Dung, "A Method to Estimate and Analyze the Performance of a Grid-Connected Photovoltaic Power Plant," *Energies (Basel)*, vol. 13, no. 10, p. 2583, May 2020, doi: 10.3390/en13102583.

[21] I. Al Siyabi, A. Al Mayasi, A. Al Shukaili, and S. Khanna, "Effect of Soiling on Solar Photovoltaic

Performance under Desert Climatic Conditions," *Energies (Basel)*, vol. 14, no. 3, p. 659, Jan. 2021, doi: 10.3390/en14030659.

[22] D. Amalia, H. Abdillah, and T. W. Hariyadi, "Analisa Perbandingan Daya Keluaran Panel Surya Tipe Monokristalin 50wp Yang Dirangakai Seri Dan Paralel Pada Instalasi Plts Off-Grid," *Jurnal Elektro dan Mesin Terapan*, vol. 8, no. 1, pp. 12–21, May 2022, doi: 10.35143/elementer.v8i1.5187.

[23] B. Bhandari, K.-T. Lee, G.-Y. Lee, Y.-M. Cho, and S.-H. Ahn, "Optimization of hybrid renewable energy power systems: A review," *International Journal of Precision Engineering and Manufacturing-Green Technology*, vol. 2, no. 1, pp. 99–112, Jan. 2015, doi: 10.1007/s40684-015-0013-z.

[24] G. Bekele and B. Palm, "Feasibility study for a standalone solar–wind-based hybrid energy system for application in Ethiopia," *Appl Energy*, vol. 87, no. 2, pp. 487–495, Feb. 2010, doi: 10.1016/j.apenergy.2009.06.006.

[25] C. Widiasari and Rizky Fachriansyah, "Rancang Bangun Automatic Transfer Switch (ATS) Hybrid Daya PLN Dan PLTS Pada Sistem Hidroponik," *Jurnal Elektro dan Mesin Terapan*, vol. 9, no. 1, pp. 121–131, May 2023, doi: 10.35143/elementer.v9i1.5878.