Available *online* at : http://jnte.ft.unand.ac.id/

Jurnal Nasional Teknik Elektro

| ISSN (Print) 2302-2949 | ISSN (Online) 2407-7267 |

A Techno-Economic Analysis for Raja Ampat Off-Grid System

Lukman Subekti [1], Candra Febri Nugraha [1], Muhammad Arrofiq [1], Ahmad Adhiim Muthahhari[1], Budi Eko Prasetyo [2], Qurrota A'yun [1]

[1] *Department of Electrical Engineering and Informatics Engineering, Universitas Gadjah Mada, Jl. Yacaranda, Sekip Unit IV, Yogyakarta, 55281, Indonesia*
[2] *Departement of Electrical Engineering, Politeknik Negeri Malang, Jl. Soekarno-Hatta No. 9, Malang, 65141, Indonesia*

ARTICLE INFORMATION

Received: January 2, 2024
Revised: February 2, 2024
Accepted: March 25, 2024
Available online: March 31, 2024

KEYWORDS

HOMER Pro, hybrid off-grid, remote electrification, techno-economic analysis

CORRESPONDENCE

Phone: +62 81240601025

E-mail: candra.febri.nugraha@ugm.ac.id

A B S T R A C T

Indonesia, an expansive archipelagic nation with over 17,000 islands, encounters significant challenges in ensuring a sustainable and dependable electricity supply, particularly in its West Papua region. The reliance on diesel fuel for electricity generation in this area poses substantial environmental risks and incurs high costs. A comprehensive research study addressing the environmental and economic challenges associated with diesel dependence in West Papua proposed a shift towards sustainable and cost-effective solutions by advocating for adopting off-grid hybrid power systems. This study targeted Yensawai Village in the Raja Ampat Islands, employing a detailed techno-economic analysis through HOMER Pro to identify the most cost-effective system configurations. The findings indicated that the optimal setup consists of a 160 kW diesel generator, complemented by a 70.1 kW solar photovoltaic (PV) system, a 30 kW inverter, and an 80 kWh battery storage unit. This configuration not only proved to be economically viable by reducing the levelized cost of electricity (CoE) by 15.7%—achieving a CoE of $0.236/kWh compared to the base scenario's $0.280/kWh—but also highlighted the potential for similar benefits across regional systems. By focusing on the economic advantages of hybrid energy configurations, this research contributes significantly to the broader discourse on sustainability and the urgent need to reduce diesel dependence, offering a practical approach to cutting electricity generation costs in remote island communities and advancing sustainability initiatives.

INTRODUCTION

Indonesia is an archipelagic country with over 17,000 islands, home to 250 million people [1]. Characterized by a vast archipelago of islands, Indonesia faces multiple challenges in providing a sustainable electricity supply [2], especially in the eastern region. For instance, West Papua Province, comprising more than 4500 islands, has a relatively lower electrification ratio of 88.35% in 2022, below the national figure of 97.63% [3]. Due to massive costs, connecting islands to mainland electricity grids through submarine cables is a less viable option [4]. Consequently, providing electricity in an archipelago depends on isolated power systems.

Isolated power systems heavily depend on diesel fuel [5], a prominent reliance in West Papua. According to Indonesian State Electricity Company (PT PLN) reports in 2022, 56.8% of West Papua's electricity generation is sourced from fossil diesel [3]. The dependence on diesel fuel not only jeopardizes the environment due to its emissions [6] but also results in high electricity generation costs [7]. Because of these challenges, There is an urgent need for a transition towards more sustainable and cost-effective solutions.

In response to diesel fuel dependence's environmental and economic challenges, PT PLN has launched the de-dieselization program [8]. This initiative aims to systematically transition from diesel fuel generation to more sustainable and renewable energy sources [9]. One promising solution is adopting hybrid power systems, which combine diesel generators, renewable energy generation, and battery energy systems [10].

Renewable energy options for a hybrid system include solar photovoltaic (PV) [11], [12], wind turbines [13], [14], micro-hydro [15]–[17], and biomass [18], [19]. When combining these generation technologies, several factors must be considered, including technical, economic, environmental, and social aspects [20]. The optimal hybrid configuration can be obtained through optimization [21]. One widely adopted optimization tool is HOMER Pro, used in research [22].

Several researchers in recent years have conducted studies on developing electrical systems in remote areas, especially in the islands region [23]–[25]. Utilizing HOMER, Kanata *et al.* optimized a hybrid system in Sebesi Island, Indonesia, considering cost, environmental, and technical criteria. Analyzing various configurations, it identified solar-biogas-battery as the most cost-effective, with a cost of energy (CoE) of $0.286/kWh, reducing reliance on diesel by 93.6% [23]. Tran *et*

https://doi.org/10.25077/jnte.v13n1.1180.2024

al. proposed a sustainable microgrid design for Con Dao Island, Vietnam, integrating solar PV and batteries alongside diesel for a cost-effective solution. This hybrid system reduces the CoE by 20%, from 0.241/kWh to 0.193/kWh, compared to the existing diesel-based system [24]. As for Teupah Island, Indonesia, Riayatsyah *et al.* proposed an optimal hybrid diesel and PV system. The optimal configuration reduces annual operating costs by up to 29.9%, cuts CO2 emissions by 33.4%, and lowers the CoE from \$0.292/kWh to \$0.246/kWh [25].

Building upon existing research, this study tackles the challenge of electrifying remote islands in Eastern Indonesia, specifically focusing on the Raja Ampat archipelago. It proposes an off-grid hybrid system design for the region, employing a techno-economic analysis to optimize the combination of local energy resources. This optimization will be realized through HOMER Pro, specialized software for designing and evaluating hybrid power systems.

METHODS

Study Case: Yensawai Village

Yensawai Village is in the Raja Ampat Regency, West Papua Province. This location is positioned at (0° 47' 59.784" S, 589° 30' 34.668" W), as illustrated in Figure 1. This village is among Raja Ampat Islands, one of the archipelagic regions in eastern Indonesia.

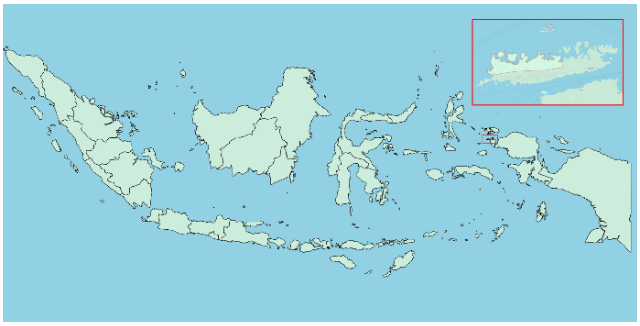

Figure 1. Yensawai Village Location

Data Modelling

Existing Electrical System

Figure 2 depicts that two diesel generators of 80 kW each cater to the electricity requirements of Yensawai. This electricity is distributed through a 400-V three-phase distribution system. Additionally, Figure 3 showcases the electrical load profile, which indicates that the load is higher in the early morning, lower during the day, and significantly increases in the evening. This profile confirms that households constitute the primary source of the electrical load.

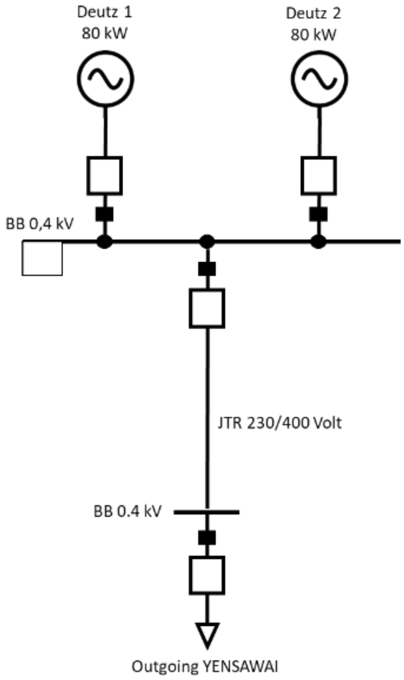

Figure 2. Single-Line Diagram of the Existing Electrical System

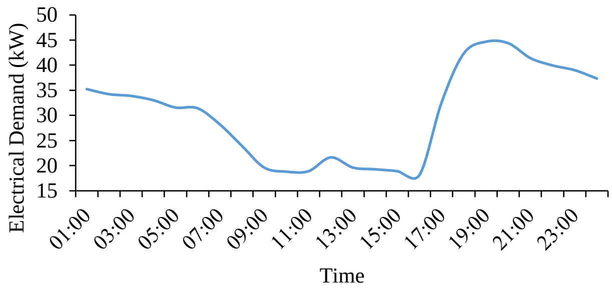

Figure 3. Average Electrical Load Demand

Renewable Energy Sources

To determine the most suitable renewable energy generation, meteorological data, including global horizontal irradiance (GHI), temperature, and wind speed, is required. HOMER Pro includes GHI and temperature data from NASA [26]. Figure 4 and Figure 5 show the monthly GHI and temperature at the location, respectively. The average solar irradiation of the location is 5.73 kWh/m^2/day, while the temperature average is 27.15 °C. In addition, the monthly wind speed profile can be observed in Figure 6. The wind speed was measured in the location, averaging at 3.21 m/s.

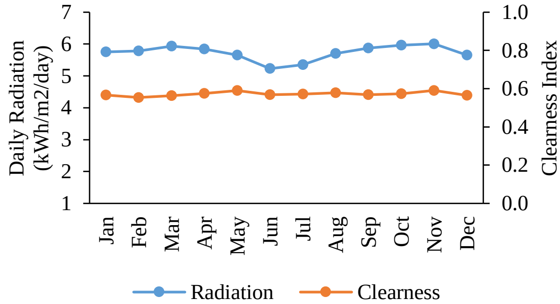

Figure 4. Daily Radiation and Clearness Index Profile [26]

https://doi.org/10.25077/jnte.v13n1.1180.2024

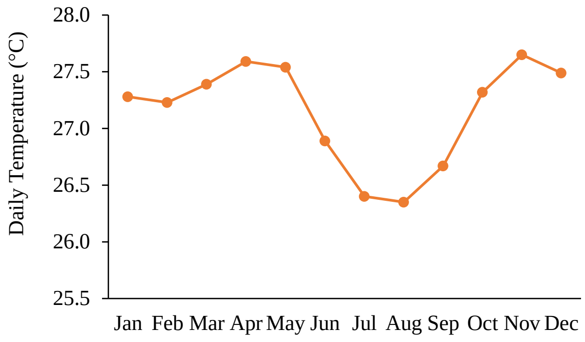

Figure 5. Daily Temperature Profile [26]

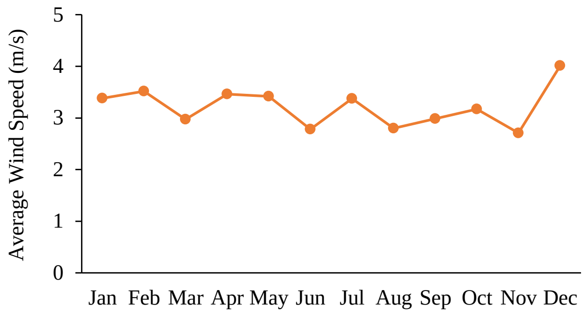

Figure 6. Average Wind Speed Profile

Proposed System Configuration

The proposed system configuration is depicted in Figure 7. Considering the day-to-day variability of the load, the estimated electricity demand of the system is 728.83 kWh/day, with a peak load of 77.90 kW. The load itself is connected to the AC bus. Generators 1 and 2, wind turbine candidates, and solar PV candidates are connected to the AC bus and the load. Solar PV can only be placed in the AC bus if installed with a dedicated solar inverter. The battery is connected to the DC bus, and the converter is used to couple the AC and DC buses.

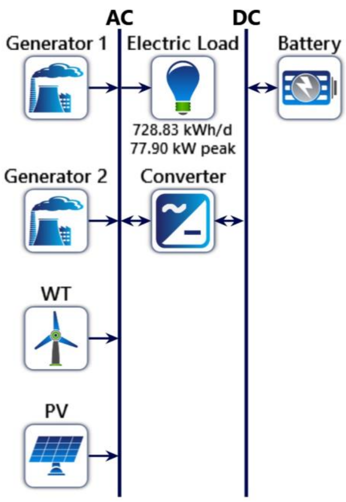

Figure 7. Proposed System Architecture

Diesel Generator

A diesel generator converts diesel fuel to electricity using a combustion process. In the existing system, there are two generators, Generator 1 and Generator 2, with a total capacity of 160 kW. Several data are specified in the model, including technical and economic parameters. The input data of the diesel generators is shown in Table 1. The diesel fuel cost is assumed to be \$0.84/l. The fuel consumption of a diesel generator depends on the fuel consumption curve, rated power, and the generated power. The fuel consumption equation is stated in (1).

Table 1. Diesel Generator Techno-Economic Data

Specifications	Value
Capacity	80 kW
Minimum load ratio	6%
Minimum runtime	60 minutes
Fuel curve intercept coefficient	0.033 l/hr/kW rated
Fuel curve slope	0.273 l/hr/kW output
Replacement cost	\$3,750
O&M cost	\$1.6/op. hour
Lifetime	20,000 op. hour

$$F = F_0 Y_{gen} + F_1 P_{gen} \tag{1}$$

Photovoltaic

Photovoltaic converts renewable energy from solar irradiance to electricity. Because of the intermittent nature of solar irradiance, the output power of PV is also intermittent. The voltage PV produces is DC; thus, an inverter is required if the PV is connected to the AC bus. A dedicated inverter is considered for the proposed system. The techno-economic data of the PV and the inverter are shown in
Table 2 and Table 3, respectively.

Table 2. Solar PV Techno-Economic Data

Specifications	Value
Peak power	380 Wp
Module efficiency	20.7%
Temperature coefficient	-0.34%/°C
Normal operating cell temperature	43°C
Derating factor	88%
Capital cost	\$354
Replacement cost	%354
O&M cost	\$5.5/year
Lifetime	25 years

Table 3. Solar Inverter Techno-Economic Data

Specification	Value
Power rating	20 kW
Capital cost	\$2,142
Replacement cost	\$2,142
Lifetime	15 years

Various factors, including the derating factor, solar irradiance, temperature coefficient, and panel temperature, influence a PV's output power. The output power is calculated using Equation (2).

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}} \right) [1 + \alpha_P (T_c - T_{c,STC})] \tag{2}$$

Wind Turbine

Another type of renewable energy generator considered in the modeling is a wind turbine, which converts kinetic energy from the wind to electricity. The output power of a wind turbine is influenced by the wind speed, which the wind turbine's power

https://doi.org/10.25077/jnte.v13n1.1180.2024

curve can describe. The power curve describes how much power will be produced at a certain wind speed in standard temperature and pressure (STP) conditions. The power curve used in this study is shown in Figure 8. To calculate the actual power output of the wind turbine, HOMER Pro uses (3) to convert power output in STP condition to actual condition. The wind turbine specifications are shown in Table 4.

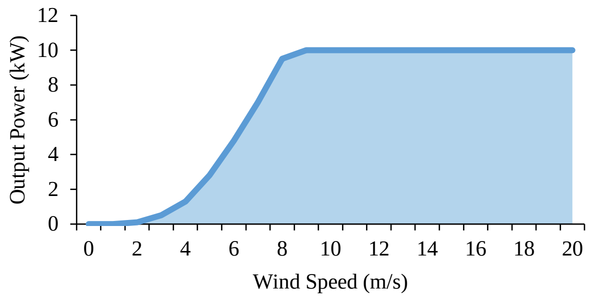

Figure 8. Wind turbine power curve [27]

Table 4. Wind Turbine Generator Techno-Economic Data

Specifications	Value
Power rating	10 kW
Hub height	30 m
Capital cost	$63,952
Replacement cost	$25,581
O&M cost	$56/year
Lifetime	20 years

$$P_{WTG} = \left(\frac{\rho}{\rho_0}\right) P_{WTG,STP} \quad (3)$$

Battery Converter

Due to the absence of grid connection in an isolated system, converter play a crucial role as voltage and frequency regulators, essential for creating a self-contained power grid [28]. This capability is commonly referred to as "grid-forming". This study chooses a 30-kW bi-directional grid-forming battery converter as a candidate. This converter supports various battery types, such as lead-acid, lithium, and sodium-ion batteries, with a voltage ranging from 150 to 750 V. The techno-economic data of the battery converter is shown in Table 5.

Table 5. Battery Converter Techno-Economic Data

Specifications	Value
Capacity	30 kW
Efficiency	95%
Capital cost	$8,000
Replacement cost	$8,000
Lifetime	15 years

Battery

Li-Ion batteries with a capacity of 1 kWh and a voltage of 6 V are selected. The number of batteries in a series is determined by considering the converter's input voltage range. A DC bus voltage of 480 V is chosen in this configuration, resulting in a series connection of 80 batteries. The techno-economic data of the battery is shown inTable 6.

Table 6. Battery Techno-Economic Data

Specifications	Value
Capacity	1 kWh
Energy throughput	3,000 kWh
Initial SoC	100%
Min. SoC	20%
Capital cost	$550
Replacement cost	$550
O&M cost	$10/year
Lifetime	15 years

Economic Parameter

In the economic analysis conducted by HOMER, several assumptions are made, including inflation rate, nominal discount rate, and project lifetime. The assumptions are provided in Table 2. Besides that, there are several terms to be input and evaluated in the project. Some of the terms are explained as follows.

Interest Rate

HOMER Pro calculates the discount rate, which converts one-time expenses to annualized costs using (4) [29].

$$i = \frac{i' - f}{1 + f} \quad (4)$$

Net Present Cost

The net present cost (NPC) is the present value of all costs over the project duration minus the present value of all revenues. The project costs include construction, operation, and maintenance costs, while the revenues include salvage value. The basic Equation of NPC is shown in (5) [29].

$$NPC = -C_{cap} + \sum_{n=0}^{R_{proj}} \frac{C_n}{(1+i)^{R_{proj}}} \quad (5)$$

Levelized Cost of Energy

Levelized cost of energy (CoE), expressed in units of $/kW, is the yearly cost of producing electricity divided by the total electric load served. The CoE equation is shown in (6) [29].

$$COE = \frac{C_{ann,tot}}{E_{served}} \quad (6)$$

Internal Rate of Return

The internal rate of return (IRR) is the discount rate at which the base case and the optimal configuration NPC are equal. This can be identified by finding the discount rate that results in zero difference of NPC between the base case and optimal configuration [29].

Return on Investment

The return on investment (ROI) is calculated by dividing the average yearly difference between the base case and optimal configuration nominal cash flows by the difference in capital cost of those configurations. The Equation is shown in (7) [29].

$$ROI = \frac{\sum_{n=0}^{R_{proj}} C_{n,ref} - C_n}{R_{proj}(C_{cap} - C_{cap,ref})} \quad (7)$$

Payback Period

The payback period is the years required for total income to equal the initial investment. Calculating the payback period of the optimal configuration is relative to the base case configuration. The time required to recover the difference in investment costs between the optimized and base case systems is defined as the simple payback period.

RESULTS AND DISCUSSION

Optimization Result

The top five most optimal systems based on the NPC are shown in Table 7. In the best scenario, the configuration consists of a 160 kW diesel generator, 70.1 kW solar PV, 30 kW inverter, and 80 kWh battery. Due to the inadequate wind energy potential in the studied area, the wind turbine candidate has not been selected. This configuration can achieve a renewable energy generation fraction of 29.6%. Meanwhile, the base case scenario, i.e., scenario with only two diesel generators, is ranked 5th with no renewable energy generation portion. These results highlight how using a hybrid system of different renewable energy sources is economically feasible and more efficient than using only a diesel-fueled generator.

Electrical Energy Generation

Figure 9 and Figure 10 illustrate the power generated by Generator 1 and Generator 2 over a year. The horizontal axis represents the number of days, while the vertical axis represents the number of hours per day. The power output is illustrated using a heatmap. Throughout the year, only Generator 2 has been operated, while Generator 1 has not been operated at all. The result shows that the system can supply the load with only one generator, while the other can be the backup. In addition, Generator 2 is only operated from 6:00 PM to 6:00 AM the following day. This totals 187,168 kWh of energy per year and 5493 operational hours. Meanwhile, the PV fulfills the daytime load.

The electricity generation from the PV is depicted in **Error! Reference source not found.**. Due to converter size limitation, the installed capacity of 70.1 kW has a maximum output of 40.0 kW. It produced energy amounting to 107,303 kWh per year, equaling a capacity factor (CF) of 17.5%. The obtained CF falls within the expected PV CF in Indonesian, ranging from 15% to 19% [30]. The summary of monthly energy generation based on its energy source is depicted in Figure 12. Despite its high fuel cost, the system's electricity generation from diesel generators is still dominant compared to PV.

Figure 13 displays the battery state of charge (SoC). The battery's state of charge tends to be lower in the morning because of the high demand and low energy generation from the photovoltaic (PV) system. As a result, the battery gets discharged to meet the demand, reducing generator energy generation. Conversely, the SoC is relatively high in the afternoon due to the high PV electricity generation when the load is low. The battery generates 13,419 kWh of energy throughput annually, with losses of 1,414 kWh.

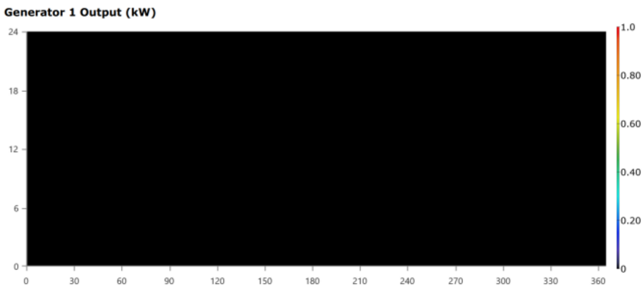

Figure 9. Generator 1 Electrical Energy Generation

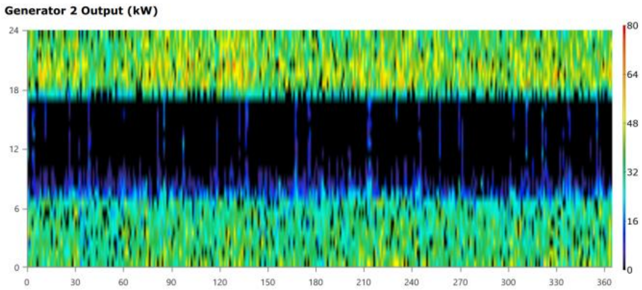

Figure 10. Generator 2 Electrical Energy Generation

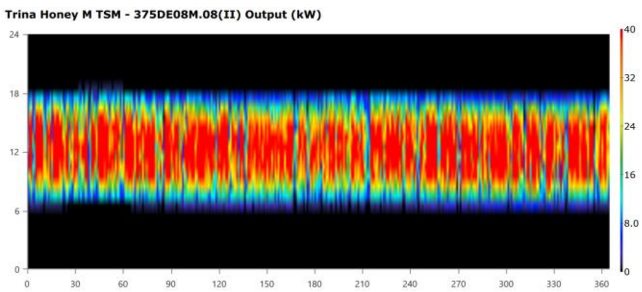

Figure 11. PV Electrical Energy Generation

Table 7. Top-five Yensawai system optimal configuration

Rank	Generator 1 (kW)	Generator 2 (kW)	PV (kW)	WT (kW)	Battery (kWh)	Converter (kW)	NPC ($M)	CoE ($/kWh)	Ren. Frac. (%)
1	80	80	70.1	0	80	30	0.73	0.236	29.6
2	80	80	66.9	10	80	30	0.77	0.250	32.8
3	80	80	35.3	0	0	0	0.81	0.263	16.6
4	80	80	31.9	10	0	0	0.86	0.277	19.7
5	80	80	0	0	0	0	0.87	0.280	0

https://doi.org/10.25077/jnte.v13n1.1180.2024

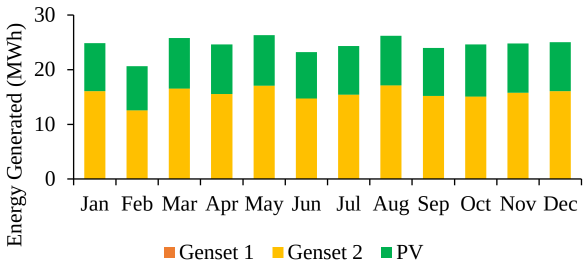

Figure 12. Monthly Electricity Production

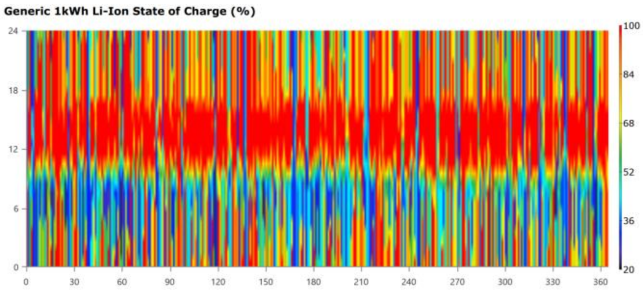

Figure 13. Battery State of Charge

Economic Evaluation

Table 8 shows the economic comparison between the base and optimized scenarios. The base case scenario yields an NPC of \$0.87 million with a CoE of \$0.280/kWh. This configuration requires no initial investment (CAPEX) with a yearly O&M cost (OPEX) of \$74,419. On the other hand, the optimized scenario yielded an NPC of \$0.73 million with a CoE of \$0.236/kWh. This configuration requires an initial investment (CAPEX) of \$121,625 and a yearly O&M cost (OPEX) of \$52,437. The CoE of the optimal scenario is 15.7% lower than that of the base case scenario. Moreover, compared to the average diesel generator CoE in similar regions, which is around \$0.313/kWh, it is much lower. This result shows that the same configuration may benefit the other systems in the area by reducing the generation cost.

Table 9 summarizes several economic parameters of the optimal scenario compared to the base case. This system has a relatively short payback period of 5.4 years with an IRR of 17.4% and an ROI of 13.5%. This means that the initial investment in the system can be regained in a relatively short period. Additionally, the economic viability of this configuration is further elaborated by the significant annual operational cost savings of \$21,982 when contrasted with the base case scenario. These economic indicators underscore the tangible financial advantages of hybrid configuration.

Figure 14 illustrates the cost components in the optimal scenario. The first and second most dominant cost components are the diesel fuel cost and O&M cost. This underlines that the energy generation from diesel generators mainly causes the higher energy cost in isolated regions. In contrast, the PV system investment cost is only ranked third. With the development of PV technology and its decreasing price, the energy cost can be much lower in the future.

Table 8. NPV, CAPEX, and OPEX of Optimal and Base Case System

Parameter	Base Case	Optimal
NPC (\$M)	0.87	0.73
CoE (\$/kWh)	0.280	0.236
CAPEX (\$)	0	121,625
OPEX (\$/year)	74,419	52,437

Table 9. Comparative Economy Analysis between Optimal and Base Case Systems

Parameter	Value
IRR (%)	17.4
ROI (%)	13.5
Simple payback (years)	5.40
Discounted payback (years)	6.68
Operation cost savings (\$/year)	21,982

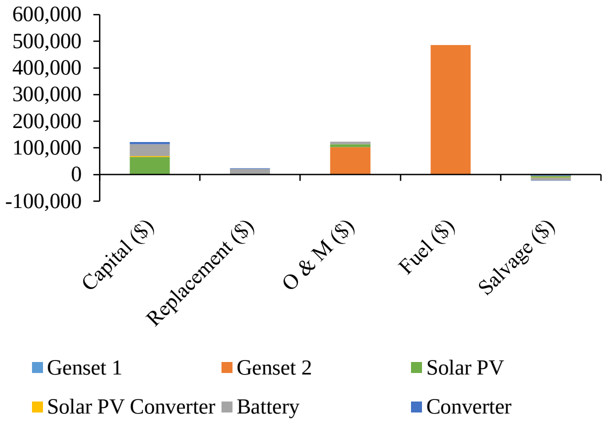

Figure 14. Project Cost Components

Comparison with Previous Works

This section provides a comparative analysis between the current study's findings and those of previous studies in the same area, specifically focusing on hybrid off-grid systems for island regions. Table 10 presents a comprehensive overview of the results from the earlier research and the current study, highlighting key aspects such as optimal configuration and economic metrics.

Kanata *et al.* identified the optimal isolated system configuration for Sebesi Island, Indonesia, comprising a 100 kW biogas generator, 69.5 kW PV, and a 49 kWh battery, catering to a peak load of 50.6 kW. The corresponding optimal Net Present Value (NPV) and Cost of Energy (CoE) were found to be 0.93 M\$ and 0.286/kWh, respectively [23]. Tran *et al.*, in their study on Con Dao Island, Vietnam, determined that a configuration consisting of a 40 kW diesel generator, 67.5 kW PV, and a 40 kWh battery resulted in the minimum NPV of 0.68 M\$ and CoE of 0.193/kWh [24]. Examining Teupah Island, Indonesia, Riayatsyah *et al.* concluded that the most cost-effective configuration involves a 160 kW diesel generator, 274 kW PV, and a 76 kWh battery, resulting in an NPV of 1.39 M\$ and a CoE of 0.246/kWh [25]. In the current study, the investigation of Raja Ampat Islands, Indonesia, indicated that a feasible configuration includes a 160 kW diesel generator, 70.1 kW PV, and an 80 kWh battery. This configuration yielded an NPV of 0.73 M\$ and a CoE of 0.236/kWh.

Table 10. Comparison of the presented study with previous works

Authors	Study Case	Peak Load (kW)	Generator (kW)	PV (kW)	Wind Turbine (kW)	Battery (kWh)	NPC ($)	CoE ($/kWh)
Kanata *et al.* [23]	Sebesi Island, Indonesia	50.6	100.0	69.5	0	49.0	928,279	0.286
Tran *et al.* [24]	Con Dao Island, Vietnam	60.0	40.0	67.5	-	40.0	677,663	0.193
Riayatsyah *et al.* [25]	Teupah Island, Indonesia	162.4	160.0	274.0	0	76.0	1,393,022	0.246
Presented work	Raja Ampat Islands, Indonesia	77.9	160.0	70.1	0	80.0	731,699	0.236

The comparison between previous and current research consistently demonstrates that, in most cases, the most technically and economically viable technologies are the diesel generator, PV, and battery. This configuration effectively addresses the electrical demand throughout the day, with PV supplying energy during the morning and afternoon while the battery and diesel generator take over at night.

Contrastingly, incorporating a wind turbine is often disregarded due to its potential to result in a higher energy cost. This decision is influenced by the observed lack of sufficient wind resources in the studied locations, rendering the wind turbine less practical and cost-effective than the above-mentioned technologies.

Regarding the CoE, findings from a literature review on hybrid system planning, as outlined in [31], reveal a significant variation, ranging from 0.15 to 1.10/kWh. This variance can be attributed to diverse factors, including assumptions related to technology prices, economic factors, diesel fuel costs, and meteorological data specific to each study case. These factors influence the COE for any given case, underscoring the importance of considering multiple variables when planning a hybrid system.

It is essential to highlight that Table 10 compares results across various study cases. Its primary function is not to showcase the effectiveness of the presented method but to provide a general comparison among different scenarios. In contrast to prior studies, our research demonstrates the technical and economic feasibility of implementing the hybrid off-grid configuration tailored explicitly for the unique conditions of Raja Ampat Islands. This distinction underscores the novelty and applicability of our findings in a specific geographical context.

CONCLUSIONS

The hybrid system introduced in this study has demonstrated its capability to meet the energy demands of the Yensawai system. The configuration comprising a 160 kW diesel generator, 70.1 kW solar PV, 30 kW inverter, and 80 kWh battery stands out as the optimal scenario. This configuration achieves a notable renewable energy generation fraction of 29.6%. Furthermore, the economic assessment emphasizes the financial benefits of the optimized scenario. The base case scenario results in an NPC of $0.87 million with a CoE of $0.280/kWh. In contrast, the optimized scenario yields a reduced NPC of $0.73 million with a lower CoE of $0.236/kWh. The CoE of the optimized scenario is notably 15.7% lower than that of the base case. Comparatively, when considering the average CoE of diesel generators in similar regions, estimated at approximately $0.313/kWh, the hybrid system's CoE appears significantly more cost-effective.

The studied hybrid model in Yensawai Village, Raja Ampat Islands, indicates its economic feasibility for supplying sustainable electricity to isolated islands. This broader implication underscores its potential applicability and impact in addressing energy challenges in similar remote regions.

REFERENCES

[1] World Bank, "Population, total - Indonesia," 2022. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ID

[2] A. Syauqi, Y. W. Pratama, and W. W. Purwanto, "Sustainable energy system in the Archipelagic country: challenges and opportunities," *Energy Syst. Eval. (Volume 1) Sustain. Assess.*, pp. 49–69, 2021.

[3] PT PLN (Persero), "Statistik PLN 2022," 2023.

[4] A. M. Aguirre-Mendoza, C. Díaz-Mendoza, and J. Pasqualino, "Renewable energy potential analysis in non-interconnected islands. Case study: Isla Grande, Corales del Rosario Archipelago, Colombia," *Ecol. Eng.*, vol. 130, no. September 2017, pp. 252–262, 2019, doi: 10.1016/j.ecoleng.2017.08.020.

[5] J. Hamilton, M. Negnevitsky, and X. Wang, "The role of modified diesel generation within isolated power systems," *Energy*, vol. 240, p. 122829, 2022.

[6] F. Perera, "Pollution from fossil-fuel combustion is the leading environmental threat to global pediatric health and equity: Solutions exist," *Int. J. Environ. Res. Public Health*, vol. 15, no. 1, p. 16, 2018.

[7] M. J. B. Kabeyi, A. O. Oludolapo, and H. Teresa, "Performance analysis of diesel engine power plants for grid electricity supply," in *31st annual Southern African institute for Industrial Engineering conference, South Africa, 5th*, 2020, pp. 236–250.

[8] D. Syafrianto, K. M. Banjar-Nahor, H. Nugraha, D. F. Hakam, P. O. Hadi, and N. Hariyanto, "Optimized Hybrid Power System Configuration for the First Phase of Dedieselization Programs," *2021 3rd Int. Conf. High Volt. Eng. Power Syst. ICHVEPS 2021*, pp. 387–392, 2021, doi: 10.1109/ICHVEPS53178.2021.9601010.

[9] M. F. Sofyan, A. A. Muthahhari, A. Evindra, M. R. F. Herawan, Y. S. Perdana, and F. Sastrowijoyo, "LCOE vs

PV Penetration in Indonesia De-dieselization Program," in *2022 5th International Conference on Power Engineering and Renewable Energy (ICPERE)*, IEEE, 2022, pp. 1–5.

[10] R. Khezri and A. Mahmoudi, "Review on the state-of-the-art multi-objective optimisation of hybrid standalone/grid-connected energy systems," *IET Gener. Transm. Distrib.*, vol. 14, no. 20, pp. 4285–4300, 2020.

[11] W. Cai *et al.*, "Optimal sizing and location based on economic parameters for an off-grid application of a hybrid system with photovoltaic, battery and diesel technology," *Energy*, vol. 201, p. 117480, 2020.

[12] A. E. E. D. Selim, M. El-Shimy, and G. Amer, "Sizing methodology for hybrid solar photovoltaic/hydrogen system using deterministic balance method (DBM)-Case study in Egypt," *J. Nas. Tek. Elektro*, pp. 1–11, 2020.

[13] M. H. Jahangir, A. Shahsavari, and M. A. V. Rad, "Feasibility study of a zero emission PV/Wind turbine/Wave energy converter hybrid system for stand-alone power supply: a case study," *J. Clean. Prod.*, vol. 262, p. 121250, 2020.

[14] F. D. Wijaya, I. W. Adiyasa, and E. Winata, "Analisis Faktor Kapasitas Pembangkit Listrik Hibrida PLTB dengan PLTD di Pulau Terpencil: Studi Kasus Elat Pulau Serau Maluku," *ELKOMIKA J. Tek. Energi Elektr. Tek. Telekomun. Tek. Elektron.*, vol. 9, no. 4, p. 746, 2021, doi: 10.26760/elkomika.v9i4.746.

[15] S. Hoseinzadeh, M. H. Ghasemi, and S. Heyns, "Application of hybrid systems in solution of low power generation at hot seasons for micro hydro systems," *Renew. Energy*, vol. 160, pp. 323–332, 2020.

[16] S. S. Murni and A. Suryanto, "Analisis Efisiensi Daya Pembangkit Listrik Tenaga Mikrohidro Menggunakan HOMER (Studi Kasus PLTMH Parakandowo Kabupaten Pekalongan)," *J. List. Instrumentasi dan Elektron. Terap.*, vol. 1, no. 2, pp. 34–38, 2021, doi: 10.22146/juliet.v1i2.61282.

[17] A. N. Azizah and S. Purbawanto, "Perencanaan pembangkit listrik tenaga hibrid (PV dan Mikrohidro) terhubung grid (Studi kasus desa Merden, Kecamatan Padureso, Kebumen)," *J. List. Instrumentasi, dan Elektron. Terap.*, vol. 2, no. 1, 2021.

[18] A. Kumar and A. Verma, "Optimal techno-economic sizing of a solar-biomass-battery hybrid system for off-setting dependency on diesel generators for microgrid facilities," *J. Energy Storage*, vol. 36, p. 102251, 2021.

[19] E. A. Syawal and R. Nazir, "Optimization of the Hybrid System for Micro Hydro, Photovoltaic and Biomass Power Generation in Senamat Ulu Village Using Homer Simulation," *J. Nas. Tek. ELEKTRO*, 2021.

[20] J. Lian, Y. Zhang, C. Ma, Y. Yang, and E. Chaima, "A review on recent sizing methodologies of hybrid renewable energy systems," *Energy Convers. Manag.*, vol. 199, p. 112027, 2019.

[21] A. M. Alzahrani, M. Zohdy, and B. Yan, "An overview of optimization approaches for operation of hybrid distributed energy systems with photovoltaic and diesel turbine generator," *Electr. Power Syst. Res.*, vol. 191, p. 106877, 2021.

[22] K. A. Kavadias and P. Triantafyllou, "Hybrid renewable energy systems' optimisation. a review and extended comparison of the most-used software tools," *Energies*, vol. 14, no. 24, p. 8268, 2021.

[23] S. Kanata, S. Baqaruzi, A. Muhtar, P. Prasetyawan, and T. Winata, "Optimal planning of hybrid renewable energy system using Homer in Sebesi Island, Indonesia," *Int. J. Renew. Energy Res.*, vol. 11, no. 4, pp. 1507–1516, 2021, doi: https://doi.org/10.20508/ijrer.v11i4.12296.g8303.

[24] Q. T. Tran, K. Davies, and S. Sepasi, "Isolation Microgrid Design for Remote Areas with the Integration of Renewable Energy: A Case Study of Con Dao Island in Vietnam," *Clean Technol.*, vol. 3, no. 4, pp. 804–820, 2021, doi: 10.3390/cleantechnol3040047.

[25] 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," *Sustain.*, vol. 14, no. 16, Aug. 2022, doi: 10.3390/su14169846.

[26] National Aeronautics and Space Administration (NASA) Langley Research Center (LRac), "Prediction of Worldwide Energy Resource (POWER) Project." 2022.

[27] Ryse Energy, "E-10 Data Sheet."

[28] D. B. Rathnayake *et al.*, "Grid forming inverter modeling, control, and applications," *IEEE Access*, vol. 9, pp. 114781–114807, 2021, doi: https://doi.org/10.1109/ACCESS.2021.3104617.

[29] HOMER Energy, "HOMER Pro 3.10," 2017. https://www.homerenergy.com/products/pro/docs/3.10/index.html (accessed Sep. 01, 2023).

[30] Ministry of Energy and Mineral Resources; Danish Energy Agency, "Technology Data for the Indonesian Power Sector," no. February, pp. 1–215, 2021, [Online]. Available: https://ens.dk/sites/ens.dk/files/Globalcooperation/technology_data_for_the_indonesian_power_sector_-_final.pdf

[31] S. Bahramara, M. P. Moghaddam, and M. R. Haghifam, "Optimal planning of hybrid renewable energy systems using HOMER: A review," *Renew. Sustain. Energy Rev.*, vol. 62, pp. 609–620, 2016, doi: 10.1016/j.rser.2016.05.039.

NOMENCLATURE

F_0	intercept coefficient of the fuel curve (l/hr/kW rated)
F_1	slope of the fuel curve (l/hr/kW output)
Y_{gen}	rated capacity of the generator (kW)
P_{gen}	generator's power output (kW)
Y_{PV}	rated capacity of the photovoltaic array under standard test conditions (kW)
f_{PV}	derating factor (%)
$\bar{G}_T$	solar irradiance hitting the PV array (kW/m^2)
$\bar{G}_{T,STC}$	solar irradiance under standard test conditions (1 kW/m^2)
α_P	temperature coefficient of power (%/°C)
T_c	temperature of the photovoltaic cell (°C)
$T_{c,STC}$	temperature of the photovoltaic cell under standard test conditions (25 °C)
P_{WTG}	the wind turbine output power (kW)
$P_{WTG,STP}$	the wind turbine output power at STP (kW)
ρ	the real air density (kg/m^3)
ρ_0	the real air density at STP (1.225 kg/m^3)
i	real discount rate (%)
i'	nominal discount rate (%)
f	expected inflation rate (%)
C_{cap}	capital cost of the selected system
C_n	nominal annual cash flow
R_{proj}	project lifetime (year)
$C_{ann,tot}$	the system's total annualized cost ($/year)

E_{served}	the total electrical load served (kWh/year)
$C_{n,ref}$	nominal annual cash flow for the base case system
R_{proj}	project lifetime (year)
$C_{cap,ref}$	capital cost of the base case system

AUTHORS BIOGRAPHY

Lukman Subekti

Lukman Subekti is a lecturer in the Department of Electrical Engineering and Informatics, Universitas Gadjah Mada. He received both the B.Eng. and M.Eng. degree in Electrical Engineering from Universitas Gadjah Mada. His specific research interest is in power systems.

Candra Febri Nugraha

Candra Febri Nugraha is a lecturer in the Department of Electrical Engineering and Informatics, Universitas Gadjah Mada. He received both the B.Eng. and M.Eng. degree in Electrical Engineering from Universitas Gadjah Mada. His specific research interests include power system operation and planning, optimization, renewable energy integration, and smart grids.

Muhammad Arrofiq

Muhammad Arrofiq is a lecturer in the Department of Electrical Engineering and Informatics, Universitas Gadjah Mada. He received both the B.Eng. and M.Eng. degree in Electrical Engineering from Universitas Gadjah Mada, Indonesia, and the Ph.D. degree from Universiti Teknologi Petronas. His specific research interest includes control engineering and network engineering.

Ahmad Adhiim Muthahhari

Ahmad Adhiim Muthahhari is a lecturer in the Department of Electrical Engineering and Informatics, Universitas Gadjah Mada. He received both the B.Eng. and M.Eng. degree in Electrical Engineering from Universitas Gadjah Mada. His specific research interests include energy planning, power system planning & reliability, and renewable energy.

Budi Eko Prasetyo

Budi Eko Prasetyo is a lecturer in the Department of Electrical Engineering, Politeknik Negeri Malang. He received both the B.Eng. and M.MT. degrees from Institut Teknologi Sepuluh Nopember. His specific research interest is in power systems.

Qurrota A'yun

Qurrota A'yun is an alumnus of the Department of Electrical Engineering and Informatics, Universitas Gadjah Mada. She received the B.Eng. degree in Applied Electrical Engineering.

https://doi.org/10.25077/jnte.v13n1.1180.2024