Towards Becoming Energy-Independent Village: A Case Study of Solar Rural Electrification in Lalumpe Village, Indonesia

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https://doi.org/10.5109/7323270

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 10, pp.246-251, 2024-10-17. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

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Abstract: *This study explores the potential of solar power as a means to achieve energy autonomy in a rural Indonesian village. The research involves gathering and analyzing data through the Hybrid Optimization Model for Energy Renewable (HOMER), focusing on a case study in Lalumpe, a fishing village in Indonesia. Situated on the Eastern seaboard of the Minahasa region on Sulawesi Island, Lalumpe's remote location makes it an ideal candidate for renewable energy electrification under the Energy Independent Village initiative. A comprehensive techno-economic assessment of the proposed model, which employs a centralized off-grid power station, will be conducted and presented as a recommendation for the solar energy village scheme. Future research will delve into alternative renewable energy options for the village, such as a photovoltaic hybrid system for rural electrification.*

Keywords: Energy Independent Village; Solar Rural Electrification; Indonesia

1. INTRODUCTION

Specific care must be provided to meet the need for green energy in rural and coastal areas while reducing environmental damage. As much as possible, we must reduce our dependence on the electric grid. As a result, research on the use of renewable energy sources for the creation of alternative types of energy is essential. Energy policies should also encourage the innovation in an energy-independent community, which is an important goal.

Lalumpe Village is located on the eastern seaboard of the Minahasa region on Sulawesi Island, Indonesia. The village is situated at latitude 050 33' 20.8" north and longitude 1270 09' 6.8" east. The village occupies 3.2 square kilometers and is home to 55 households, comprising approximately 250 residents. The remote nature of the village poses significant challenges for grid connectivity, making it an ideal candidate for off-grid solar solutions.

The location of the case study is shown in Figure 1.

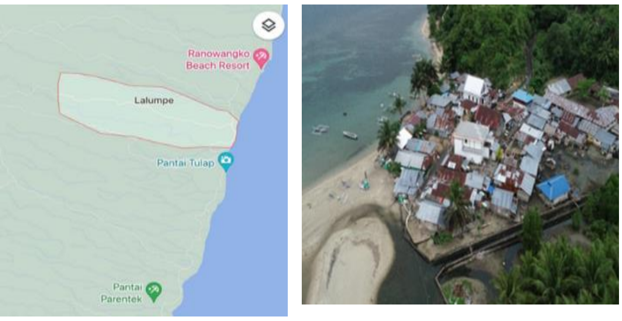

Fig. 1. Map of Tulaun sub-urban in the Lalumpe village

This study analyzes the viability of powering a remote coastal village using only photovoltaic cells as part of a PV system. Recent research indicates that Indonesia's renewable energy resources have the potential to serve as a viable alternative power supply for the island. According to a recent study, the northern half of the island of Sulawesi may be one of the best locations in Indonesia for solar power generation [1].

As shown in Figure 2, the location experiences a tropical climate with a distinct dry and wet season. Average annual solar radiation is 5.52 kWh/m²/day, making it suitable for solar power generation. The clearness index varies throughout the year, peaking in September at 0.60, which indicates the potential for substantial solar energy harvesting during this period.

Fig. 2. Solar radiation potential in Lalumpe Village

The exploration of renewable energy and indigenous resources has emerged as an imperative consideration for sustainable communities. A multitude of extant research has undertaken a comprehensive examination of the economic, environmental, and socio-well-being aspects of biomass energy utilization, culminating in a diverse array of outcomes [2].

A previous study [3] presented a comparative analysis aimed at addressing the energy requirements of a rural Indonesian village, specifically Tulaun Village, Lalumpe, Indonesia. The research employs various scenarios of rural power systems, predicated on four distinct models of the micro hydro system. The initial model posits an energy-independent village, entirely supplied by micro hydro power. The subsequent model integrates micro hydro power with the grid. The third model amalgamates micro hydro power, grid, and diesel. The final model is a tripartite combination of micro hydro power, solar photovoltaics (PV), and battery storage. The data pertaining to load demand were procured in accordance with the electricity needs of 55 households within the village community. The Hybrid Optimization Model for Renewable Energy (HOMER) was chosen as the analytical tool for this techno-economic feasibility study.

This project aims to assess the viability of a centralized off-grid Photovoltaics (PV) energy system for the remote Tulaun sub-village. Lalumpe is a fishing village on the eastern coast of the province of Minahasa, in its most eastern region.

The article's structure is as follows: This is the first section, the introduction. The second section presents a concise literature overview of previous work evaluating the PV system with HOMER in various locations. The third section outlines the research methods employed, and these approaches include load profile data, resource data, and system component input. Section 4 presents the simulation results provided by HOMER for the Lalumpe village case study, while section 5 concludes with a list of recommendations.

2. LITERATURE REVIEWS

The National Renewable Energy Laboratory's HOMER (Hybrid Optimization of Multiple Energy Resources) program can be used to analyze a power system infrastructure model for island populations. The arrangement was designed with island communities in mind (NREL).

It was decided that various models for building electrical infrastructure would be tested as part of the HOMER project to see if they were useful. In addition to solar, wind, hydro, and fuel cell technologies, the HOMER optimization software can examine design choices for off-grid and grid-connected systems. Because of these qualities, the software can be used in remote, stand-alone, and distributed generating applications [4].

Studying the simulations of power system generator models has been done using HOMER as a method of investigation. For the HOMER initiative, Dursun et al. [5] researched a micro-grid wind-PV hybrid system meant for a remote community of fifty households. An analysis of the practicality of a solar-wind hybrid energy system was conducted by Bekel and Bjorn [6] and published using the HOMER program. A study was done to see if such a system may be financially sustainable. Molla et al. investigated the viability of solar, hybrid, and wind energy sources in Bangladesh's more remote and rural areas [7]. It was determined by Al-Badi [8] that a wind-photovoltaic-diesel hybrid power plant on the island of Al Hallaniyat would be useful.

As a result of HOMER's implementation in various research initiatives, numerous studies on renewable energy sources have been published. There have been studies of villages in Bangladesh and Ethiopia, but Himri and his colleagues [9] focus on a small community in Algeria that uses a hybrid power system. Although hybrid renewable energy projects have been executed, research on an inaccessible Indonesian coastal village has yet to be made public.

The author conducted feasibility studies at various locations, including Talaud Island and Bunaken Island, utilizing HOMER. These studies aimed to develop a hybrid power plant system consisting of PV-Wind-Diesel-Battery to meet the needs of the Miangas island community [10]. An investigation into the feasibility of simulating a solar house system using HOMER is detailed in [11], with the findings summarized in that report. However, researching the potential applications of solar energy in the coastal areas around Lalumpe village in the Minahasa district poses challenges due to its remote location. The significant impact that regional geography and cultural norms have on energy consumption patterns makes the location of the community crucial. [12] HOMER's unique algorithm enables the optimizer to determine the most efficient and cost-effective system for the specified load and conditions [13]. To demonstrate the program's modeling capabilities, microsystem simulations were conducted, with two different types of simulations performed [14]. Furthermore, the accuracy of the HOMER modeling was found to be comparable to that of the actual measurements, indicating its reliability in predicting real-world scenarios. To ensure the validity of the HOMER modeling, additional experiments were conducted to compare its results with those obtained from other reliable prediction methods, confirming its high accuracy in predicting real-world scenarios.

Hybrid renewable energy systems containing different renewable energy sources may be a more reliable option for supplying electricity in remote places. Adding solar and wind power systems makes it possible to minimize the amount of diesel oil required and, consequently, the running costs [15]. A well-balanced system can deliver steady outputs from a range of sources [16] while limiting dependency on seasonal fluctuations and optimizing the usage of renewable energy sources.

PV (photovoltaic) panels convert solar energy to direct current (DC), whereas inverters reverse the current's direction (DC to AC) (AC). As long as renewable energy sources can meet demand, batteries can store any excess energy produced. A battery backup is given if the system needs more power but cannot obtain it from renewable sources [17].

3. METHODS

Using the community of Lalumpe as a case study, we will conduct techno-economic research on PV power generation for rural residents. http://www.homerenergy.com was produced by the Department of Energy's National Renewable Energy Laboratory and is accessible online. Renewable and alternative energy sources can be harnessed with this method. Demographic statistics and the typical daily electrical load in Lalumpe are provided as input data.

Table 1 provides the following data, as shown below (Tulaun sub-village) at Lalumpe village in North Sulawesi Province of Indonesia.

Table 1. Communities Data in Tulaun Sub-Village at Lalumpe

Number of People	250
Number of Households	55
Daily Load Average	403 kWh

To establish the viability of a solar energy system at a particular site, one must consider the amount of solar radiation available at that place. On the NASA website, the amount of solar radiation emitted by the village of Lalumpe was discovered by entering its latitude and longitude into a search box. The average daily radiation from the sun is 5,6 kilowatt-hours per square meter. The clearness index of Lalumpe can also be found in the HOMER data set [18]. The clarity index is calculated by dividing the amount of extraterrestrial radiation above the Earth's atmosphere by the amount of global solar radiation received at the surface of the Earth.
Table 2 summarizes the obtained data on solar radiation, the cleanliness index, and wind speed in the Lalumpe village.

Table 2. Average Monthly Solar Radiation and Clearness Index in Lalumpe Village

Month	Solar Radiation ($KWh/m^2/day$)	Clearness Index
January	5.2	0.53
February	5.3	0.53
March	5.7	0.53
April	5.8	0.57
May	5.6	0.57
June	5.3	0.57
July	5.5	0.54
August	5.8	0.50
September	6.2	0.60
October	6.0	0.54
November	5.4	0.54
December	5.3	0.54

The daily profile of electricity demand for Tulaun sub-urban that located in Lalumpe village communities for one year that used in HOMER simulation is presented in Figure 3.

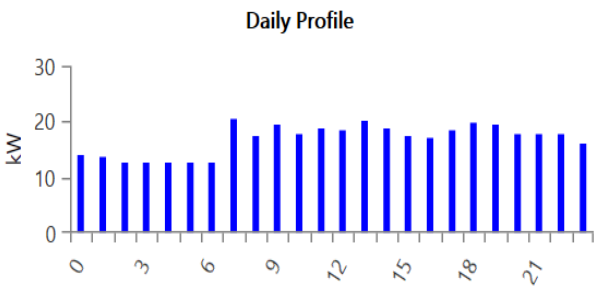

Fig. 3. The daily load profile for remote communities in Tulaun subvillage at Lalumpe

The Figure 3 consists of two distinct graphical representations: a daily profile. The daily profile is depicted as a bar graph, showing vertical bars representing measurements or values over individual days. The vertical axis likely represents a quantifiable metric. The seasonal profile is presented as a box-and-whisker plot, which displays variability across different time scales. The horizontal axis likely represents dates or day indicators.

Data collection involved direct measurement and monitoring of household electricity usage in Lalumpe Village over a period of one year. Daily load profiles were created by aggregating data from all 55 households, with usage patterns observed for both residential and communal facilities. Solar irradiance and climatic data were sourced from the NASA Surface Meteorology and Solar Energy database, ensuring accurate and reliable inputs for the HOMER simulations.

The HOMER (Hybrid Optimization Model for Multiple Energy Resources) software was utilized to simulate various solar photovoltaic (PV) system configurations for Lalumpe Village. Input parameters included solar radiation data, load profiles, battery specifications, and economic factors such as capital costs and operational expenses. The optimization process involved running multiple scenarios to identify the most cost-effective and technically feasible solution for the village's energy needs. Key constraints included ensuring a reliable power supply and minimizing excess electricity generation.

The HOMER software that developed by The National Renewable Energy Laboratory (NREL) can build off-grid or grid-connected Distributed Generator (DG) systems. An extensive system with many technological choices and variants can be analyzed for its technical and economic feasibility using the algorithms it employs. Features like optimization and sensitivity analysis stand out. A load profile, component specifications (including size and number), resource data, economics, system control, emissions, and other criteria are all HOMER system configuration modeling inputs.

In addition, HOMER system configuration modeling takes into account additional factors. Based on the load profile, the system components, and the energy sources of the system, HOMER provides a cost-effective way to develop the system's most cost-effective model.

The HOMER simulation evaluated two primary scenarios for the PV system in Lalumpe Village:

Scenario 1: A 100% solar PV system with a total capacity of 151 kW.

Scenario 2: An enhanced PV system with a capacity of 218 kW.

Figure 4 and Figure 5 depict the expected power supply of Lalumpe's electrical demand, including 100 percent PV, a battery, and a converter for scenario 1 and scenario 2 respectively.

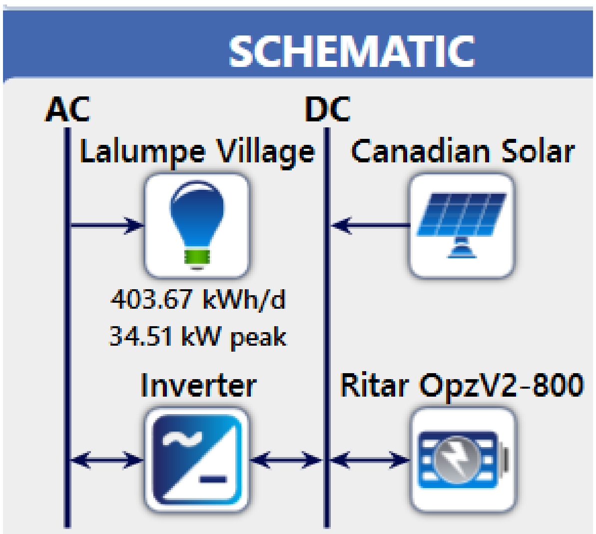

Fig. 4. The proposed of 100% PV power generation model for Tulaun sub-village for scenario 1

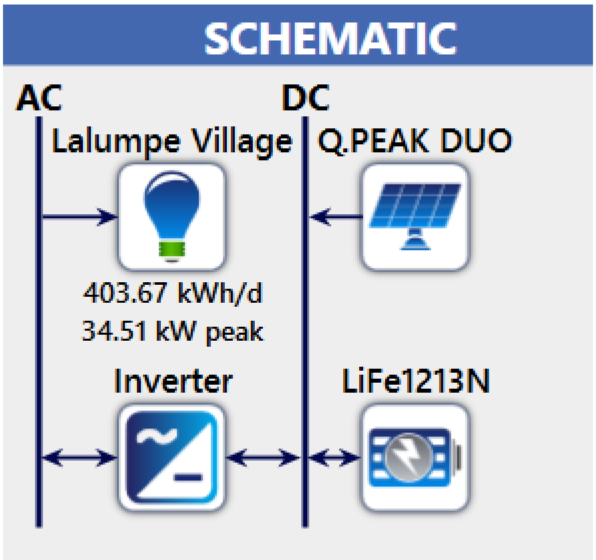

Fig. 5. The proposed of 100% pv power generation model for Tulaun sub-village for scenario 2

The system employs both alternating and direct current buses. A battery positioned on the DC bus side of the system stores the solar PV-generated energy. Whenever it is necessary to convert DC to AC, an MS-PAE converter is applied. In the design for scenario 1 with solar energy systems, 211 units of Ritar OpzV2-800 Ah batteries and Canadian solar panels are utilized. In the design of scenario 2, which included solar power systems, the Qpeak Duo and 242 units of battery Life 1213N were utilized.

Figure 6 and Figure 7 show a software interface for modeling a kinetic battery system for scenario 1 and scenario 2 respectively.

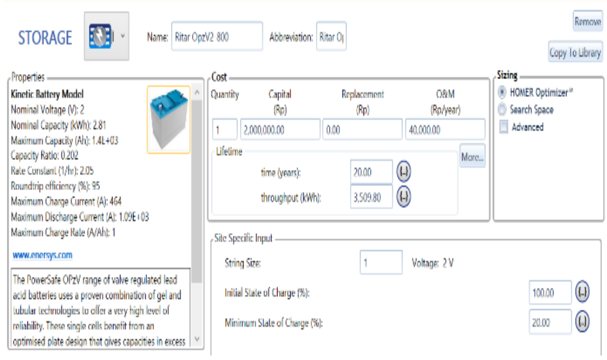

Fig. 6 Battery sizing system for scenario 1

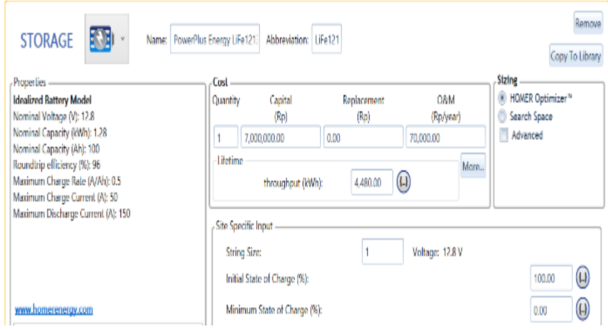

Fig. 7 Battery sizing system for scenario 2

4. RESULTS & DISCUSSIONS

The research utilizes the HOMER program to enhance its findings. The energy model is run for each potential system configuration to estimate the installation and maintenance costs during the life of the project. The following table displays the results of the HOMER simulation in terms of energy capacity, energy cost, net present value, and energy production. An energy-independent village in the Tulaun sub-village has been chosen for a 100 percent PV model power system. Table 4 displays the anticipated capacity and associated costs.

Table 3. The Capacity, COE, NPC and Energy Production of The Proposed PV System Components

Items	Scenario 1 (Low)	Scenario 2 (High)
Capacity of PV	151 kW	218 kW
Cost of Energy (COE)	Rp. 839	Rp. 1940
Net Present Cost (NPC)	Rp. 2.374.175.027	Rp5.485.899.487
Energy Production	250.609 kWh/year	351.542 kWh/year
Excess Electricity	96.819 kWh/year	198.609 kWh/yr

HOMER determines, for each load, how much suitable component capacity is required to construct a reliable power system. The capacity of the power plant component is defined by the amount of electricity produced annually, the amount of capital required, the overall Net Present Cost (NPC), and the cost of energy per kilowatt-hour (COE). According to the modeling results of a 100 percent photovoltaic system, scenario 1 has a COE of Rp 839 / kWh, whereas scenario 2 has an NPC of Rp 5,585,899,487 and a cost of energy (COE) of Rp 1,940 / kWh.

Based on the results of the HOMER simulation, Figure 8 compares the respective energy production levels of the two scenarios. There are two scenarios, designated 1 and 2.

The result in Figure 8 indicates that both scenario 1 and scenario 2, the electric production is slightly higher than electric consumption.

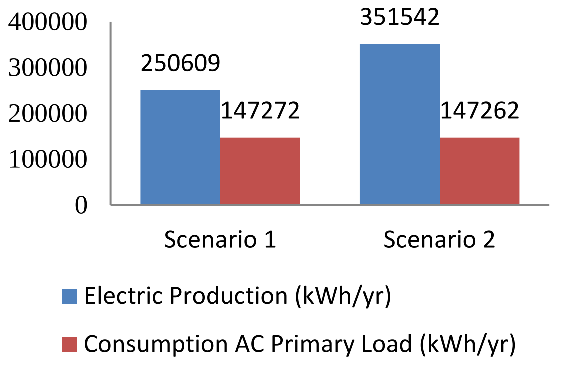

Fig. 8. The comparison of energy production between scenario 1 and scenario 2 for the proposed system

Based on the HOMER simulation result, the comparison of annualized cost between scenario 1 and scenario 2 are presented in Figure 9.

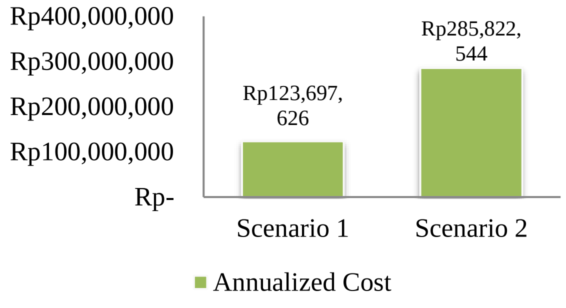

Fig. 9. The comparison of annualized cost between scenario 1 and scenario 2

In Scenario 1, the annualized cost reaches approximately Rp123,697,626 (Indonesian Rupiah) while scenario 2 has a significantly higher annualized cost, approximately Rp285,822,544.

The financial analysis indicates that Scenario 1, with a lower initial investment and operational cost, provides a more economical solution for immediate implementation. However, Scenario 2, despite its higher upfront cost, offers greater capacity and future-proofing benefits, potentially supporting community expansion and increased electricity usage.

Using HOMER, the possibility of a PV-system as the only source of energy for 55 families was explored (Hybrid Optimization Model for Electric Renewable). The monthly average daily radiation at the location is anticipated to be 5.52 kWh/m^2. The examination of the potential of a centralized PV system revealed that the amount of electricity generated per year is between 250.609 kWh and 351.542 kWh, which is sufficient to meet the demand of houses.

The implications of using a centralized PV off-grid system for the rural and remote village of Lalumpe include providing a viable source of independent power supply for the community. This system has been determined to be able to meet the electricity demand of the village, as shown by the simulation results. Additionally, the study suggests that this system can support green economic policies and serve as a preliminary analysis for future research on infrastructure deployment for renewable energy-based power systems in rural and isolated coastal villages. The adoption of this system could contribute to the Energy Independent Village program and align with the Sustainable Development Goals (SDGs).

Implementing a solar PV system in Lalumpe Village contributes significantly to reducing greenhouse gas emissions by displacing diesel generator usage. The reduction in CO_2 emissions is estimated to be approximately 150,000 kg annually for Scenario 1 and 210,000 kg for Scenario 2. This aligns with Indonesia’s national goals for renewable energy integration and carbon footprint reduction.

This study demonstrates the viability of using solar PV systems to achieve energy independence in remote rural villages. The findings indicate that both proposed scenarios can effectively meet the electricity demands of Lalumpe Village, with Scenario 2 providing additional capacity for future growth. Future research should focus on integrating other renewable energy sources, such as wind or biomass, to further enhance energy resilience and sustainability in similar communities.

This study has the potential to serve as a preliminary analysis for future research on infrastructure deployment for renewable energy-based power systems in rural and isolated coastal villages. The remote village's adoption of the proposed centralized PV power electricity generation system as an alternate means of fulfilling the village's electricity demand could help both the Energy Independent Village program and the Sustainable Development Goals. The adoption of solar PV systems in Lalumpe Village aligns with Indonesia’s national goals for renewable energy integration and carbon footprint reduction, contributing to the broader Sustainable Development Goals (SDGs). Specifically, it supports SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action).

The successful implementation of a solar PV system in Lalumpe Village serves as a model for other remote communities in Indonesia and similar regions worldwide. The study highlights the feasibility of achieving energy independence through renewable resources, thus contributing to sustainable development goals. However, challenges such as initial capital investment, maintenance of solar infrastructure, and community training need to be addressed to ensure long-term success.

There are some recommendations could be improved for further planning and implementation toward Energy independent Village, such as policy development, community engagement as well as further research. Governments should formulate supportive policies and incentives for the adoption of renewable energy systems in rural areas. Local authorities should engage communities in the planning and implementation process to ensure acceptance and effective utilization of the solar PV systems. Continued research on hybrid energy systems and storage solutions can further enhance the reliability and cost-effectiveness of rural electrification projects.

5. CONCLUSION

The Lalumpe case study provided a plan for designing and implementing solar energy in remote and rural areas. A HOMER simulation was used to aid in the execution of this technique. In terms of technological and economic analysis, this proposed design, which includes two choices for 100% solar energy consumption, proves the ability of a solar energy village to support green economic policies.

A model of a PV power plant system capable of satisfying the demand for electricity in rural regions can be built using the results of a simulation run using the HOMER application. The model will concentrate on the Tulaun sub-village of Lalumpe village in particular. Furthermore, it is possible for the proposed Solar Energy Village System to compare the Cost of Energy (COE), Net Present Cost (NPC), and Operating Cost for Scenarios 1 and 2. A centralized PV off-grid system has been determined to be a viable source of independent power supply for the rural and remote area of Lalumpe village.

Further investigation into alternative renewable energy options for the village, such as a photovoltaic hybrid system for rural electrification. The study suggests that future research should explore integrating other renewable energy sources, such as wind or biomass, to further enhance energy resilience and sustainability in similar communities.

ACKNOWLEDGEMENT

This study is supported by the funding from DIPA of Sam Ratulangi University.

6. REFERENCES

[1] M.Rumbayan, A. Abudureyimu, K. Nagasaka, “Mapping of solar energy potential in Indonesia using artificial nural networks and geographic information system”, Renewable and Sustainable Energy Reviews 16, 2012, 1437-1449.

[2] Shamal Chandra Karmaker, Md. Matiar Rahman , Shahadat Hosan and Bidyut Baran Saha, The Impact of Biomass Energy Consumption on Human Development: Evidence from Asian Countries, Proceeding of International Exchange and Innovation Conference on Engineering & Sciences (IEICES) 6 (2020).

[3] M. Rumbayan, R. Rumbayan, C. Pasiowan, S. Elkana, N. V Panjaitan, Comparative study of four micro hydro model systems for powering the sub-village of Tulaun Lalumpe Minahasa in Indonesia, Proceeding of International Exchange and Innovation Conference on Engineering & Sciences (IEICES) 8, pp.155-160, (2022).

[4] A. H Mamaghani, S. A.A Escandon, B. Najafi, A. Shirazi, F. Rinaldi, “Techno-economic feasibility of photovoltaic, wind, diesel and hybrid electrification systems for off-grid rural electrification in Colombia”, Renewable Energy 97, 2016, pp 293-305.

[5] B. Dursun, C. Gokcol, I. Umut, E. Ucar, S. Kocabey, Techno-economic evaluation of a hybrid PV-wind power generation system, International Journal of Green Energy 10 (2013), pp117-136.

[6] G. Bekele and B. Palm, Feasibility study for a standalone solar–wind-based hybrid energy system for application in Ethiopia, Applied Energy 87 (2010), pp 487–495.

[7] M.S.H Lipu, S. Uddin, M.A.R Miah, A Feasibility Study of Solar-Wind-Diesel Hybrid System in Rural and Remote Areas of Bangladesh, International Journal of Renewable Energy Research, Vol. 3, No.4, 2103.

[8] Al-Badi, A.H, “Hybrid (solar and wind) energy system for Al Hallaniyat Island electrification”, International Journal of Sustainable Energy 30 (4), 2011; 212-222.

[9] Himri Y, Stambouli AB, Draoul B, Himri S. Techno Economical Study of Hybrid Power System for a Remote Village in Algeria. Energy 2008; 33 (7); 1128-1136.

[10] Meita Rumbayan, Yosuke Nakanishi, Prospect of PV-wind-diesel hybrid system as an alternative power supply for Miangas Island in Indonesia, International Journal of Smart Grid and Clean Energy, vol. 8, no. 4, July 2019: pp. 402-407.

[11] Meita Rumbayan, Sherwin R U Sompie, Dirko G S Ruindungan and Naomi V Panjaitan, Design of a Photovoltaics Stand-Alone System for a Residential Load in Bunaken Island Using HOMER. IOP Conf. Ser.: Earth Environ. Sci. 927 012039, 2021.

[12] Brandon H. Newell. 2010. The Evaluation Of Homer As A Marine Corps Expeditionary Energy Pre-Deployment Tool. Thesis. Master Of Science In Electrical Engineering. Naval Postgraduate School.

[13] D. Naves, C. Silva, S. Connors, Design and implementation of hybrid renewable energy systems on micro-communities: A review on case studies, Renewable and Sustainable Energy reviews 31 (2014), pp 935-936.

[14] S. Khare, P. Nema, P. Baredar,” Solar-Wind Hybrid Renewable Energy System: A Review”, Renewable and Sustainable energy Reviews 58, 2016, pp 23-33.

[15] A.H Mamaghani, S.A.A Escandon, B. Najafi, A. Shirazi, F. Rinaldi, “Techno-economic feasibility of photovoltaic, wind, diesel and hybrid electrification systems for off-grid rural electrification in Colombia”, Renewable Energy 97, 2016; 293-305.

[16] J.J Ding, J.S Buckeridge, “Design considerations for a sustainable hybrid renewable energy system”, IPENZ Transactions, Vol. 27, No. 1 pp. 1-5, 2000.

[17] G. Rohani and M. Nour, “Techno-economical analysis of stand-alone hybrid renewable power system for Ras Musherib in United Arab Emirates”, Energy 64 (2014); 828-841.

[18] Z. Chmiel Z, S. C Bhattacharya, “Analysis of off-grid electricity system at Isle of Eigg (Scotland): Lessons for developing countries”, Renewable Energy 81 (2015); 578-58