Journal of Advanced Technology and Multidiscipline (JATM)
Vol. 03, No. 02, 2024, pp. 44-53
e-ISSN: 2964-6162

# Fulfillment of Bawean Electricity with a Hybrid Renewable Energy System using HOMER

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***Abstract*— Access to energy and electricity drives the economy, including industrial activities in isolated areas. Currently, the shrimp industry on Bawean (an isolated area) is facing the problem of many unserved power needs. Thus, this study aims to design hybrid renewable energy for the productive sector. There are two configurations, namely configuration 1 (PV SYSTEM, WIND TURBINE SYSTEM, GRID, BESS) and configuration 2 (PV SYSTEM, GRID, BESS), which find the potential for solar and wind radiation very suitable for renewable energy sources. Thus, based on the HOMER simulation, the best alternative solution is configuration 1 which utilizes PV SYSTEM (8.9 MW), 2 Wind Turbine System (1.6 MW), and 3 BESS, resulting in the lowest LCOE value of 0.137 $/kWh. The results of configuration 1 can meet the electricity needs of Bawean Island and shrimp ponds with the lowest LCOE value, so it can potentially increase productive sectors such as shrimp ponds.**

***Keywords*—Bawean Island, HOMER, Hybrid Renewable Energy System, Isolated Area, Shrimp Farming Industry**

## I. Introduction

Access to energy and electricity promotes economic growth and boosts community productivity. Increasing access to energy and electricity can assist alleviate poverty by increasing production among the poor [1]. Underdeveloped areas, typically within a province, have lower levels of development than other areas on a national scale due to factors such as economic conditions, human capital, infrastructure, local government budgets, geographic location, accessibility, disaster vulnerability, and conflict [2],[3]. In Indonesia, these locations are referred to as 3T *(Terdepan, Terluar, Tertinggal)* and isolated areas. 3T and isolated places in Indonesia are located in remote areas with little access to the center, stifling regional economic progress.

One of these is the shrimp farming sector in 3T and isolated parts of Indonesia, which faces substantial obstacles due to its remote location, inadequate infrastructure, and intermittent electrical supply. These problems frequently impede the productivity and profitability of shrimp growers. One of them works in the shrimp farming industry in an isolated part of Bawean Island. Residents' shrimp harvest from traditional shrimp farming has not been optimal, due in part to a lack of adequate energy supply. Furthermore, the shrimp harvest must be immediately marketed on Bawean Island or sold outside of the island, although there is no cold storage for the shrimp harvest. Thus, the availability of electricity is extremely important for the shrimp farming industry activities on Bawean Island.

Currently, the electrical needs of Bawean Island (an isolated location in East Java) are fulfilled by two primary power plants: the Diesel Power Plant (PLTD) and the Gas Engine Power Plant. However, over the last year, Bawean Island's electricity needs have not been met properly; even approximately 600 customers with a power requirement of 2,316,000 VA have been unable to install new or add electricity, disrupting various industrial, economic, and business activities on the island [4]. Furthermore, the power required by unserved customers is significant, but the PLTD power plant in the area has been unable to install new equipment. This will have a negative influence on the shrimp farming business, particularly in the past year many entrepreneurs have started to participate in the shrimp farming industry on Bawean Island but have been constrained by the inadequate supply of electricity. In fact, in accordance with the National Medium-Term Development Plan (RPJMN) 2020-2024 Presidential Regulation Number 18 of 2020, revitalization of shrimp and milkfish ponds needs to be carried out to increase aquaculture production and encourage economic growth in the regions.

To address this issue, implementing a hybrid renewable energy system appears to be a promising alternative. The problem of insufficient power needs on Bawean Island and the impossibility to construct PLTD power plants stems from PLN's existing commitment to lowering emissions to net zero by 2060, hence the utilization of renewable energy on Bawean Island is critical. Reliable, sustainable, and clean energy generation benefits not only the economy and development, but also the environment and climate [5],[6].

Hybrid renewable energy systems, which combine multiple renewable energy sources such as solar and wind power with energy storage, provide a sustainable alternative by providing consistent and cost-effective energy supply while lowering the risk of weather-related power outages [7],[8]. Rural electrification would boost regional development and economic progress by enabling the utilization of power generated in productive sectors via hybrid renewable energy systems [9]. This is in agreement with Presidential Regulation Number 22

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Journal of Advanced Technology and Multidiscipline (JATM)
Vol. 03, No. 02, 2024, pp. 44-53
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of 2017 on the National Energy General Plan, which focuses on the development of local resource-based energy in remote areas through the New and Renewable Energy Initiative (EBT). Thus, by employing hybrid renewable energy accessible in the 3T region or isolated areas, this system can provide a reliable and clean electricity supply for the shrimp farming industry.

This study aims to conduct a techno-economic analysis of hybrid renewable energy systems for productive activities in the shrimp farming industry in isolated areas in Indonesia, with a case study on Bawean Island. This study is the first to analyze the techno-economics of hybrid renewable energy for the shrimp farming industry in isolated areas. This is different from previous studies that designed electricity systems in India [10], Iran [11], Qatar [12], and have not been implemented for industrial activities in isolated areas. In addition, other methods have also been developed in designing energy systems, such as genetic algorithms [13],[14]. Furthermore, this study uses the HOMER method to find the optimal configuration of renewable energy systems for electricity supply. By evaluating the technical and economic feasibility, as well as considering the environmental benefits of this system, this study seeks to address the problem of unmet electricity supply availability and also the potential for utilizing renewable energy solutions in isolated areas, which are beneficial for policymakers, investors/entrepreneurs, and shrimp farmers in the local area.

## II. FUNDAMENTAL THEORY

### *2.1 Renewable Energy*

According to Law Number 30 of 2007, renewable energy is defined as energy that is continually generated from renewable and sustainable sources, such as sunshine, wind, geothermal, bioenergy, water, and the movement and temperature differential of ocean strata [16]. Solar energy is a vast natural resource with two primary energy sources that can be turned into electricity: heat energy content and photon energy [17]. Heat energy is converted into electrical energy using Concentrated Solar Power (CSP) technology, which collects heat energy as an energy source. Photovoltaic (PV) technology converts photon energy into electricity using materials such as semiconductors and electron transport.

### *2.2 Solar Energy*

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### *2.3 Wind Energy*

Wind energy is derived from airflow caused by temperature and pressure differences that are unevenly distributed across the earth's surface. Wind can be used to generate electricity, which is produced by wind turbines that use aerodynamic principles of rotor blades.

### *2.4 Battery Energy Storage System (BESS)*

BESS improves renewable energy availability by absorbing and releasing power at different periods. This system may overcome the intermittent nature and swings in renewable energy intensity, balancing and increasing output, demand, and power quality [17].

### *2.5 Renewable Energy Modeling*

HOMER, RETScreen, HybSim, HySim, Ihoga, and other currently available software can be used to model a hybrid renewable energy system (HRES). Among existing software, the Hybrid Optimization Model for Electric Renewables (HOMER) is one of the most user-friendly for optimizing system settings [18]. HOMER software can be used to simulate power generation systems by accounting for energy balance, system configuration, engineering, and economic analysis using optimization models. In addition, HOMER can model systems with energy balance calculations for 8760 hours per year. HOMER simulation can also determine whether to use batteries or existing generators on an hourly basis. In addition, HOMER can display the system's lifecycle cost, cost accounting analysis, and the operation and maintenance of each component's energy flow in any configuration.

## III. METHOD

A flowchart outlining the general research process is shown in Figure 1.

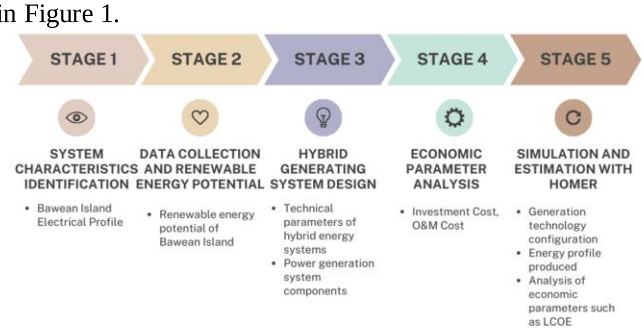


Figure 1. Research Flowchart

### *3.1 System Characteristics Identification*

Stage 1 involves identifying the system characteristics or electricity profiles on Bawean Island, which includes installed power data, generator load profiles, and energy consumption.

*Research Area*

Bawean Island is located in the Java Sea, precisely in the north of Gresik City which is officially under the administration of Gresik Regency, East Java Province. On Bawean Island there are 2 sub-districts and 30 villages, with a population of 80,289

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e-ISSN: 2964-6162

people. PT PLN is currently trying to continue to increase the electrification ratio, especially in the 3T areas and isolated areas. PT PLN in the 2021-2030 RUPTL explains the strategy for providing electricity in rural areas by developing existing distribution networks or developing power plants whose energy sources utilize the local renewable energy mix (EBT) (if the area is still isolated). In line with the Government's policy to increase EBT generation, the PLTD to EBT conversion program is one of the initiatives carried out to reduce imported fuel and increase power plant efficiency (especially in isolated areas). In East Java, there are 7 isolated subsystems that will be supplied with electricity by PLN, one of which is Bawean [16]. In addition, Bawean Island is one of 200 locations for converting PLTD to EBT.

*3.2 Data Collection and Renewable Energy Potential*

Stage 2 analyzes the potential for renewable energy, specifically solar and wind energy.

According to the identification of local energy potential, Bawean Island has sufficient solar and wind energy resources. For example, the Global Horizontal Irradiation (GHI) value of 1,836.6 kWh/m2 per year on Bawean Island, Sangkapura District, as well as the Direct Normal Irradiation (DHI) value of 1,377.9 kWh/m2 per year, are used to determine the thermal potential of solar heat. Furthermore, the average wind speed in Sangkapura District is 3.34 m/s at a height of 10 meters, 4.73 m/s at 50 meters, and 5.6 m/s at 100 meters. This is in accordance with the prospective wind speed, which can be used properly if it exceeds three m/sec.

*3.3 Hybrid Generating System Design*

The design of a hybrid power plant system is implemented in Stage 3. Two primary procedures are involved in the design of a hybrid power plant system: the computation of the hybrid system's technical parameters in the specifics of the hybrid energy system requirements and the information about the power plant system's components.

*3.4 Economic Parameter Analysis*

The fourth stage includes an economic evaluation of the hybrid energy system, by planning investment costs and O&M costs. Then, the data processing process is carried out using the HOMER application for the simulation and optimization process in Stage 5. The results of the data processing will be analyzed and the process of identifying the configuration of the power plant technology and economic analysis will be carried out, such as calculating LCOE, NPV SYSTEM, ROI, IRR and PP to determine the extent to which the invested project will provide an impact on profits and benefits for investors, and determine whether the project is feasible to implement or not.

*3.4.1 Net Present Value (NPV)*

When translated to the comparable value at present using a specific interest rate, the net cash value in the future is known as the net present value, or NPV. The NPV value serves as the basis for determining a project's economic viability; a positive NPV suggests that the project is both possible to execute and has a positive profit value. The investment value has a negative influence and cannot be executed, though, if the NPV is negative. Additionally, a zero net present value (NPV) indicates that the project investment has no financial impact and generates neither profit nor loss. As a result, a project must be assessed for its potential for profit or harm in order to inform decision-making regarding the project's viability, which includes taking the NPV value into account. The calculation of the NPV value can be shown in Equation 3.1.

$$NPV = \sum_{t=1}^{n} \left(\frac{Ct}{(1+i)^t}\right) - C_0 \qquad (3.1)$$

When,
NPV = Net Present Value
Ct = Cash flow in year t
$C_0$ = Initial investment value in year 0
i = Interest rate
t = year of cash flow
n = project life

*3.4.2 Internet Rate of Return (IRR)*

Interest rates and the anticipated earnings of a project are compared using the Internal Rate of Return (IRR). Aside from IRR criteria, the MARR (Minimum Attractive Rate of Return) value is taken into account while assessing economic viability. Based on economic considerations, the project is feasible if the IRR value exceeds the MARR value. The calculation of the IRR value can be shown in Equation 3.2.

$$\sum_{t=1}^{n} \left(\frac{Ct}{(1+i)^t}\right) - C_0 = 0 \qquad (3.2)$$

When,
Ct = Cash flow in year t
$C_0$ = Initial investment value in year 0
i = Interest rate
t = year of cash flow
n = project life

*3.4.3 Payback Period*

Payback Period is a measure that indicates how long it takes to meet a project's investment expenses, or, in other words, how long it takes to recover the investment value issued. This is significant because it influences the amount of project profitability, which occurs when investment costs are met and covered. The calculation of the Payback Period value can be shown in Equation 3.3.

$$\text{PP} = \frac{Cf}{Co} \qquad (3.3)$$

When,
PP = Payback Period
Cf = Total cash flow up to year n
Co = Initial investment value

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### *3.4.4 Levelized Cost of Electricity (LCOE)*

The Levelized Cost of Electricity (LCOE) is a standard economic statistic used to assess the costs of producing various alternative power generation methods. The LCOE evaluates and compares different types of power generation by dividing the entire investment cost by the total electrical energy produced during operation. The calculation of the LCOE value can be shown in Equation 3.4.

$$\text{LCOE} = \frac{I_0 + \sum_{t=1}^{n} \frac{Mt+Ft}{(1+r)^t}}{\sum_{t=1}^{n} \frac{Et}{(1+r)^t}} \qquad (3.4)$$

When,
LCOE = Levelized Cost of Electricity (Rp/kWh)
$I_0$ = Project investment value in the first year (Rp)
Mt = Operational and maintenance value in year t (Rp)
Ft = Fuel consumption value in year t (Rp)
Et = Value of electrical energy produced in year t (Rp)
r = Interest rate (%)
n = Economic life/service life (years)

### *3.5 Modeling Hybrid System using HOMER*

The HOMER approach, a power system design tool that makes it easier to compare power production technologies in different applications, is used in this work [17]. The demand load profile, prospective energy sources in the form of average daily wind speed and average daily solar radiation, and other input data are needed for the HOMER simulation. The type of PV SYSTEM module, wind turbine, converter, battery, and its specifications, as well as the PV SYSTEM module's performance characteristics, including the derating factor and input parameters, are among the data pertaining to the technical parameters of the components.

## IV. RESULT AND DISCUSSION

### *4.1 Electrical Profile of Bawean Island*

Data on energy consumption and installed power at PLN ULP Bawean is very necessary in estimating the capacity of the renewable energy generator to be designed.

Table 1. Customer energy consumption in Bawean Island

| Year | Monthly average |
|---|---|
| 2020 | 2.525.371,0 |
| 2021 | 2.643.727,6 |
| 2022 | 2.707.374,3 |
| 2023 | 2.884.204,1 |

Table 1 shows that isolated islands' electricity usage increases every year. The installed power data obtained will be used to determine the utilization of the potential amount of renewable energy. Customer energy consumption data each month is relatively high compared to the power capacity generated from PLTD and PLTMG. The energy consumption data used by customers will be reprocessed to help determine how much capacity the hybrid generator is designed to have.

### *4.2 HRES Pre-Feasibility Estimation (Renewable Energy Potential of Bawean Island)*

### *4.2.1 Solar Radiation*

Solar radiation data for Bawean Island in 2023 was obtained from the Renewables.ninja website [22], which uses the NASA geographic database [18] and the Satellite Application Facility on Climate Monitoring (CM-SAF) SARAH dataset [19]. The results are shown in Figure 2, where the lowest value is 0.401 (December 2023) and the highest is 0.662 (August 2023). Furthermore, based on the daily radiation value, the highest peak is in August, with 6.75 kWh/m²/day, and the lowest is in December, with 4.23 kWh/m²/day.

Based on the analysis of the potential for renewable energy from solar radiation, the annual average of horizontal global radiation (GHI) is 5.43 kWh/m²/day. This potential for utilization is very appropriate compared to the research of Rusydi et al. [20], which has a GHI of 5.364 kWh/m²/day.

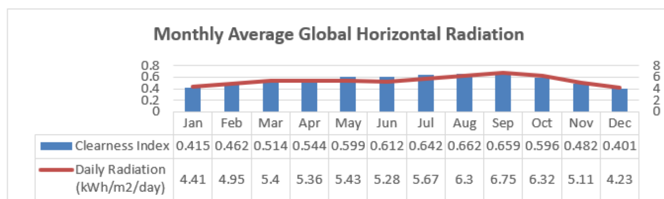


Figure 2. Potential Solar Radiation in 2023 [22]

This solar radiation data is used as input in HOMER to develop accurate designs and plans for Solar Power Plants (PV SYSTEM).

### *4.2.2 Wind Speed*

Wind speed data for Bawean Island in 2023 was also obtained from the RenewablesNinja website, which uses the NASA geographic database [19] and the Satellite Application Facility on Climate Monitoring (CM-SAF) SARAH dataset [21]. Figure 3 shows the average wind speed data, one of the renewable energy potentials on Bawean Island. The highest wind speed was 6.87 m/s in August 2024, while the lowest average wind speed was in November 2024 at 3.37 m/s, which may be less than optimal for this month.

Overall, the average wind speed value is 5.28 m/s, which has a potential for utilization that is very appropriate compared to research [22], with an average potential wind speed in other areas of 4.29 (m/s).

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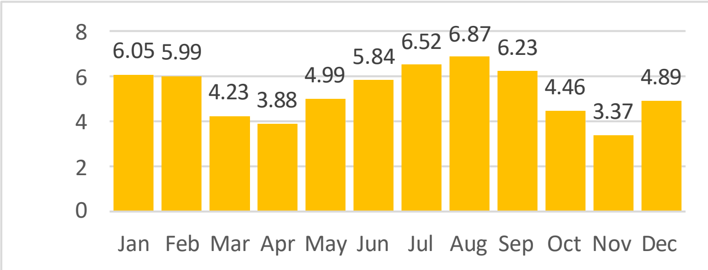



Figure 3. Average Wind Speed on Bawean Island [23]

## *4.3 Hybrid Generating System Design*

### *4.3.1 Generating Load*

Figure 4 shows a difference in the average generating load on weekends compared to weekdays, especially from 02.00 to 05.00. From 02.00 to 04.00, the average generating load on weekdays is higher than on holidays, while from 04.00 to 05.00, there is a higher average generating load on holidays. Furthermore, the load tends to be the same at other times, both weekdays and holidays. However, based on Figure 5, the average generating load on weekdays tends to be higher than on holidays. The generating load data used is data from the last 1 year. Hence, calculating the generating load is very accurate when designing additional generating capacity using renewable energy.

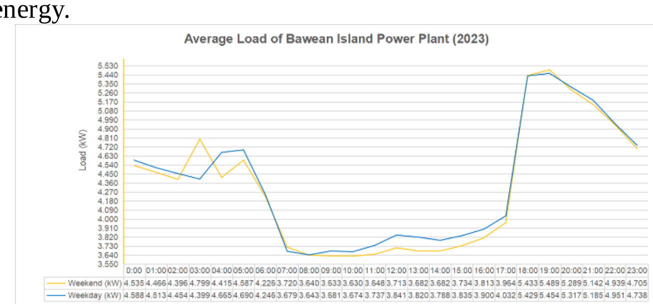
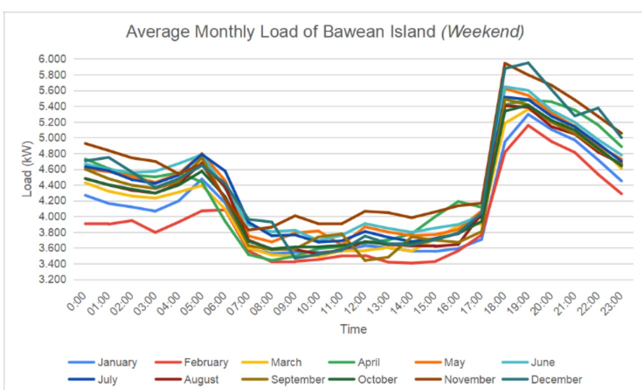
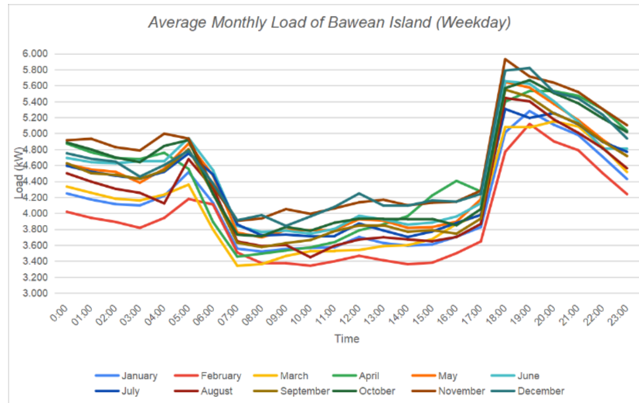



Figure 4. Average Load of Bawean Island Power Plant




(a)




(b)

Figure 5. Average Monthly Load of Power Plant: (a) Weekday, (b) Weekend

### *4.3.2 Proposed System Design*

Based on the generator design shown in Figure 6, which is made in the Homer application, it consists of several components: Grid, WIND TURBINE SYSTEM, PV SYSTEM, Converter, BESS, and Load Data. The hybrid system to be designed aims to meet the demand for electricity on Bawean Island and also limit the use of PLTD and PLTMG because both generators use fuel that is not included in renewable energy. To reduce dependence on less environmentally friendly power plants and increase the penetration of renewable energy use, the grid capacity in the Homer application is determined into four capacities (4178, 4558, 4651, 4701), with the highest capacity value of 4,701 kW.

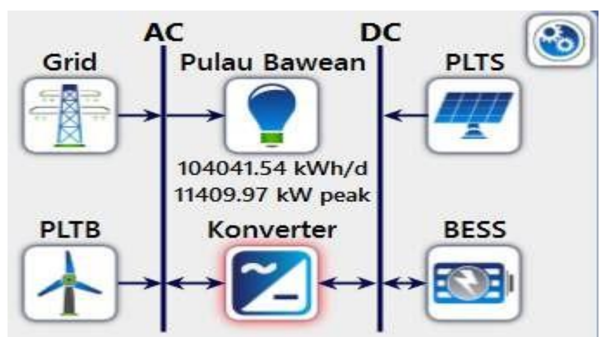



Figure 6. Representation of Proposed System Design

### *3.3.3 Technical Parameters of Hybrid Energy Systems*

This study uses various components in a hybrid-based renewable energy system consisting of PV SYSTEM, WIND TURBINE SYSTEM, converters, and energy storage systems (BESS), as shown in Table 2. The technical parameters for the specifications of the components of the hybrid-based renewable energy system are based on Marsela [24], with the following specifications.

Table 2. Technical Parameters of Components of Hybrid Renewable Energy Systems

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| Type | PV | | WT | | Converter | | BESS Generic 4-hour 1-MW Li-ion | |
|---|---|---|---|---|---|---|---|---|
| | Jinko Solar365jkm365M-72 | | Enercon-53 800 kW | | ABB PV8980-58-2000kVA-K | | | |
| Capital Cost ($) | 712.25 | /kW | 959533.74 | $/1 Unit | 1219923.30 | $/Unit | 375757.58 | Per unit |
| Replacement Cost ($) | 0 | /kW | 767626.29 | $/1 Unit | 0 | $/Unit | 375757.58 | Per unit |
| O&M Cost ($) | 8.55 | /kW/year | 9595.34 | $/1 Unit/year | 19518.77 | 100 kW$/unit/year | 3757.58 | Per unit/Year |
| Throughput | | | | | | | 296.819 | kWh |
| Nominal Voltage | | | | | | | 600 | V |
| Nominal Capacity | | | | | | | 4220 | kWh |
| Rated Capacity | 1000 | W | 800 | kW | 2000 | kW | | |
| Lifetime | 25 | | 20 | | 15 | | 15 | Year |

The solar panel used is the "Jinko Solar365jkm365M-72" type. Its investment cost is 712.25 USD/kW without replacement costs, and its annual operation and maintenance (O&M) cost is 8.55 USD/kW/year.

The Wind Power Plant (WIND TURBINE SYSTEM) uses an "Enercon-53" turbine with a capacity of 800 kW, a capital cost of 959,533.74 USD per unit, a replacement cost of 767,626.29 USD per unit, and an O&M cost of 9,595.34 USD per year. The converter component uses the "ABB PV SYSTEM8980-58-2000kVA-K" model with a capital cost of 1,219,923.30 USD per unit, without replacement costs, and an annual O&M cost of 19,518.77 USD per 100 kW per unit per year.

The BESS used is a 1 MW Li-ion battery with a storage duration of 4 hours, has the same capital and replacement costs of 375,757.58 USD per unit, and an annual O&M cost of 3,757.58 USD per unit.

*4.4 HOMER Configuration Results*

*4.4.1 Configuration 1 (PV SYSTEM/WIND TURBINE SYSTEM/GRID/BESS)*

Table 3 shows the architecture of a renewable energy system that uses solar power (PV SYSTEM), wind (WIND TURBINE SYSTEM), and battery (BESS) and is connected to the electricity grid. The main capacity consists of PV SYSTEM (8933 kW), converter (5353 kW), WIND TURBINE SYSTEM (200), and battery. Economically, this project is profitable with an IRR of 77%, an ROI of 93%, and a payback period of only 1.6 years, indicating the potential for fast and efficient returns.

Table 3. Configuration 1 (PV SYSTEM/WIND TURBINE SYSTEM/GRID/BESS)

| | Parameters | Values |
|---|---|---|
| Architecture | PV SYSTEM (kW) | 8.933 |
| | WIND TURBINE SYSTEM (Qty) | 2 |
| | BESS (Qty) | 3 |
| | Grid (kW) | 4.701 |
| | Konverter (kW) | 5.353 |
| | Dispatch | CC |
| Cost | NPC ($) | $64,7M |
| | COE ($) | $0,137 |
| | Operating cost ($) | $4,39M |
| | Initial capital ($) | $12,7M |
| System | Ren Frac(%) | 40,7 |
| | Total Fuel (L/yr) | 0 |
| PV SYSTEM | Capital cost ($) | 6.362.478 |
| | Production (kWh/yr) | 42.260.202 |

The daily profile of the system on Bawean Island shows a fairly fluctuating pattern of wind and solar potential in the area. The electricity production generated from each component, namely PV SYSTEM, is 13,841,249 kWh/year, WIND TURBINE SYSTEM is 4,839,321 kWh/year, and Grid is 23,579,632 kWh/year. PV SYSTEM and WIND TURBINE SYSTEM contribute 32.8% and 11.5% to meeting existing electricity needs.

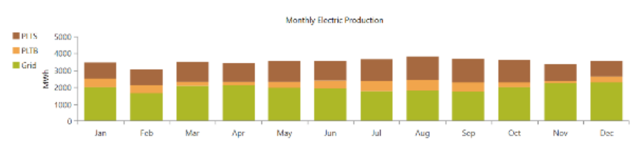


Figure 7. Monthly Electricity Production

The dispatch control strategy influences the monthly profile shown in Figure 7 as Cycle Charging (CC). This strategy allows the Battery Energy Storage System (BESS) to store energy every time the generator produces energy. When the BESS reaches the maximum State of Charge (SoC), the BESS will release energy (discharge) to meet the electricity load [25]. Therefore, the Cycle Charging pattern is generally used in off-grid systems that involve renewable energy as part of their generation.

Figure 7 shows the average monthly electricity production of the hybrid energy system. Most electricity is produced in August due to the month's high solar radiation and wind speed. In November, solar panels and the Grid produce most of the electricity. This is due to the low wind speed in that month, so the energy conversion is small.

Table 4. Battery Performance

| Parameters | Values | Unit |
|---|---|---|
| Battery | 3 | Pcs |
| String | 1 | Battery |
| Voltase bus | 600 | Volt |
| String Paralel | 3 | string |
| Autonom | 2,92 | Hour |
| Battery cost (*keausan*) | 1,33 | $/kWh |
| Nominal capacity | 12.649 | kWh |

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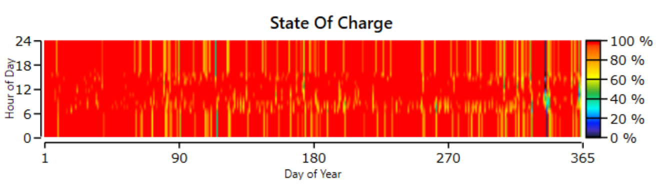
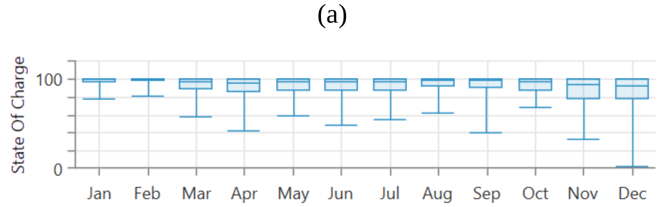
| Parameters | Values | Unit |
|---|---|---|
| Usable nominal capacity | 12.649 | kWh |
| *Throughput* during life cycle | 890.457 | kWh |
| Expected life cycle | 1,5 | Year |
| Input energy | 626.356 | kWh/Year |
| Output energy | 563.720 | kWh/Year |
| Energi lost | 62.636 | kWh/Year |
| *Annual throughput* | 594.213 | kWh/Year |

Simulation results using the HOMER application show that the battery energy storage system (Table 4) uses three battery units with a bus voltage of 600 volts and three parallel strings. With a nominal capacity of 12,649 kWh and the same usable capacity, this system has an annual throughput of 594,213 kWh/year. The expected service life of the battery is 1.5 years, with a total throughput during the service life reaching 890,457 kWh. Although the energy entering the battery system reaches 626,356 kWh/year, the energy supplied back for consumption is only 563,720 kWh/year, indicating an energy loss of 62,636 kWh/year.

The system autonomy is recorded at 2.92 hours, which means the battery can supply power for almost 3 hours without new energy input. The battery wear cost is estimated at 1.33 $/kWh, which is quite competitive considering the relatively short battery life. This analysis provides important insights into the potential use of battery systems in renewable energy schemes integrated into island electricity systems, such as Bawean, Indonesia.




(a)




(b)

Figure 8. State of Charge Profile: (a) Annual Battery, (b) Monthly Battery

From the simulation results conducted using the HOMER application, the SOC shows that the battery system operates with a reasonably stable charge level above 40%, as shown in Figure 8, and is relatively consistent throughout the year. In certain months, especially in the middle of the year (such as June to August), the SOC often reaches more than 80% capacity, indicating optimal charging during seasons with high solar radiation. Conversely, the SOC tends to be lower in months such as December. However, it remains in a stable range, indicating that even though energy production is reduced, the battery can still support electricity needs with an adequate level of autonomy. System efficiency can be seen from the annual throughput of 594,213 kWh, which indicates that the battery can store and distribute energy significantly each year.

Overall, this SOC pattern proves that the battery system is functioning effectively, maintaining a stable energy supply and reducing dependence on conventional resources or energy from the grid. However, some annual energy losses of 62,636 kWh are due to system inefficiencies.

| Quantity | PV SYSTEM Performance | Wind Performance | Unit |
|---|---|---|---|
| Capacity Measured | 8933 | 1600 | kW |
| Average Output | 1580 | 552 | kW |
| Capacity Factor | 17,7 | 34,5 | % |
| Total Production | 13.841.249 | 4.839.321 | kWh/year |
| Minimum Output | 0 | 0 | kW |
| Maximum Output | 7.783 | 1.620 | kW |
| Wind Penetration | 36,4 | 12,7 | % |
| Operating Hours | 4.269 | 8.651 | hrs/year |
| Average Cost | 0,0442 | 0,0407 | $/kWh |

Table 5. Performance of PV SYSTEM Modules and Wind Turbines

The simulation results in Table 5 show the performance of the PV SYSTEM module, with an installed capacity of 8,933 kW and an annual production of 13,841,249 kWh, with an energy cost (LCOE) of $0.0442 per kWh. The PV SYSTEM shows a peak capacity of 7,783 kW with an average capacity factor of 17.7%. Analysis of the PV SYSTEM output power graph (Figure 9 a) reveals significant variations in energy production correlated with seasons and meteorological conditions. With a total NPC of $64,745,710 and an effective annual operation of 4,269 hours, this system offers the right solution to meet energy needs with significant emission reductions.

Meanwhile, the simulation results of the hybrid renewable energy system using HOMER software (Table 5) show that the wind turbine in this system has a total installed capacity of 1,600 kW. The average power output generated by the turbine reaches 552 kW, with a capacity factor of 34.5%. This wind turbine can produce a total energy of 4,839,321 kWh in one year. With consistent energy production, the wind turbine contributes significantly to the total energy production in the hybrid system.

The power output of the wind turbine varies from 0 kW (minimum) to 1,620 kW (maximum), depending on the existing wind speed conditions (Figure 9 b). The wind turbine operates for 8,651 hours per year, so this wind turbine contributes significantly to the provision of sustainable electricity in the hybrid renewable energy system.

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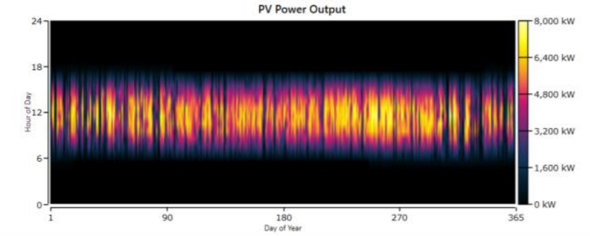
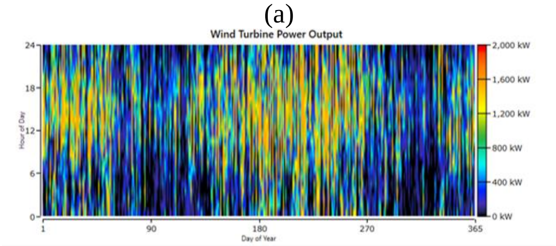
e-ISSN: 2964-6162




(a)




(b)

Figure 9. Output Results (a) PV SYSTEM Power, (b) Wind Turbine Power

*4.4.2 Configuration 2 (PV SYSTEM/GRID/BESS without WIND TURBINE SYSTEM)*

The simulation results from the HOMER application show a hybrid energy system configuration consisting of several main components, namely a Solar Power Plant (PV SYSTEM) with an installed capacity of 7,027 kW, a Battery (BESS) with a total storage capacity of 7000 kW, a Grid with a capacity of 4,701 kW, and a converter with a capacity of 7,963 kW (shown in Table 6). This system is also connected to the Grid with a generator configuration designed for dispatch control (CC) settings to maximize the efficiency of renewable energy utilization. Economically, this project is profitable with an IRR of 397%, ROI of 600%, and a payback period of only 0.3 years, indicating the potential for fast and efficient returns.

Table 6. Configuration 2 (PV SYSTEM/GRID/BESS sign WIND TURBINE SYSTEM)

| | Parameter | Value |
|---|---|---|
| Architecture | PV SYSTEM (kW) | 7.027 |
| | BESS (Qty) | 7 |
| | Grid (kW) | 4.701 |
| | Konverter (kW) | 7.963 |
| | Dispatch | CC |
| Cost | NPC ($) | $121M |
| | COE ($) | $0,284 |
| | Operating cost ($) | $9,10M |
| | Initial capital ($) | S12,5M |
| System | Ren Frac(%) | 28,9 |
| | Total Fuel (L/yr) | 0 |
| PV SYSTEM | Capital cost ($) | 5.005,293 |
| | Production (kWh/yr) | 10.888,761 |

Furthermore, in terms of economy and cost, this hybrid energy system has an annual operating cost of 9.1 million USD and an initial capital cost of 12.5 million USD. With a total NPC (Net Present Cost) reaching 121 million USD and a COE (Cost of Energy) of 0.284 USD/kWh, this system is designed to provide a competitive energy supply in the long term.

This system also has a renewable energy fraction contribution of 28.9%, which shows that almost a third of the energy needs are met by renewable energy sources. *Solar power plants* are the primary source that contributes significantly to total energy production, while wind power plants and BESS function as complements to maintain the stability of the energy supply. In this configuration, the system does not require Fuel (total Fuel = 0), indicating that all energy needs are met without dependence on fossil energy sources. The average monthly electricity production of this hybrid energy system configuration two is shown in Figure 10. The electricity produced is relatively stable every month throughout the year, with the average monthly electricity production above 3000 MWh.

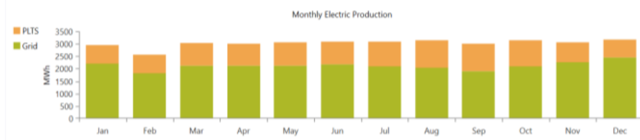



Figure 10. Monthly Electricity Production

Table 7 shows the battery performance configuration. Based on this configuration, the battery system can provide autonomous power for 6.81 hours, meaning the battery can supply power without additional energy sources during that period. In addition, the expected lifetime of this battery system is relatively short, which is 0.512 years (about six months), meaning the battery needs to be replaced after that period to maintain optimal system performance.

Table 7. Battery Performance Configuration

| Parameter | Value | Unit |
|---|---|---|
| Battery | 7 | Pcs |
| String | 1 | Battery |
| Bus Voltage | 600 | Volt |
| String Parallel | 7 | string |
| Autonomy Period | 6.81 | Hours |
| Battery Wear Cost | 1.33 | $/kWh |
| Nominal Capacity | 29.515 | kWh |
| Usable Nominal Capacity | 29.515 | kWh |
| Throughput over service life | 2,077,733 | kWh |
| Expected Service Life | 0.512 | Years |
| Energy In | 4,252,465 | kWh/Year |
| Energy Out | 3,851,035 | kWh/Year |
| Storage Depletion | 25.105 | kWh/Year |
| Energy Loss | 426,535 | kWh/Year |
| Annual Throughput | 4,059,348 | kWh/Year |

Table 8. PV SYSTEM Panel Performance

| Quantity | Value | Unit |
|---|---|---|
| Measured Capacity | 7027 | kW |
| Average Output | 1243 | kW |

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| | | |
|---|---|---|
| Average Output per Day | 29832 | kWh/day |
| Capacity Factor | 17.7 | % |
| Total Production | 10888.761 | kWh/year |
| Minimum Output | 0 | kW |
| Maximum Output | 6123 | kW |
| PV SYSTEM Penetration | 28.7 | % |
| Operating Hours | 4269 | Hours/year |
| Average Cost | 0.0442 | $/kWh |

The PV SYSTEM performance output (Table 8) in this simulation shows that the Jinko Solar365JKM365M-72 solar power system with an installed capacity of 7,027 kW has an average output of 1,243 kW and an average daily output of 29,832 kWh/d with a capacity factor of 17.7%. The total annual production of this system reaches 10,888,761 kWh/year. Furthermore, the PV SYSTEM Power output results regarding the variation of daily output based on sunlight intensity, where the maximum output achieved is 6,123 kW with a PV SYSTEM penetration of 28.7%, show a significant contribution from the PV SYSTEM to the overall energy system. A levelized cost of only $0.0442/kWh shows a meager and efficient energy production cost, making this system economically feasible.

*4.4.3 Comparison of HOMER Configuration Results*

The Bawean or Grid Generation BPP (Kepmen 169, 2021) is 0.187 $/kWh, equivalent to IDR 2,910,094. This value is a tariff that has received subsidies from the government so that compared to the actual BPP of Bawean generation, it is more expensive (BPP Subsidy < Actual BPP).

The results of the simulation of this research configuration using HOMER obtained two alternative configurations: configuration 1 (PV SYSTEM/WIND TURBINE SYSTEM/BESS/GRID) and configuration 2 (PV SYSTEM/BESS/GRID), with the results shown in Table 9. Based on the 2021-2030 RUPTL, there is a plan to build a 5 MW PV SYSTEM, and the realization will be carried out in 2024, but until now, there has been no realization. Since the current solar radiation potential is much better than that of 2020, configuration 1 (PV SYSTEM/WIND TURBINE SYSTEM/BESS/GRID) with a PV SYSTEM capacity that can be utilized at 8.9 MW is possible. Furthermore 2022, based on the PLN Nusantara Power project planning report, a WIND TURBINE SYSTEM of 1 MW and a battery capacity of 3 MW will be built on Bawean Island. So, based on the selected configuration (PV SYSTEM/WIND TURBINE SYSTEM/BESS/GRID) with a WIND TURBINE SYSTEM capacity of 1.6 MW, it is also realistic to realize. Thus, configuration 1 (PV SYSTEM/WIND TURBINE SYSTEM/BESS/GRID) is the best alternative for a hybrid renewable energy system with the lowest LCOE value of 0.137 $/kWh.

Table 9. Comparison of HOMER Configuration Results

| Configuration | Grid (Kepmen 169, 2021) | PV SYSTEM/WIND TURBINE SYSTEM/BESS/GRID | PV SYSTEM/BESS/GRID |
|---|---|---|---|
| PV SYSTEM (kW) | - | 8933 | 7027 |
| WIND TURBINE SYSTEM (Unit) | - | 2 | - |
| BESS (Unit) | - | 3 | 7 |
| Grid (kW) | - | 4701 | 4701 |
| Konverter (kW) | - | 5353 | 7963 |
| LCOE ($/kWh) | 0,187 | 0,137 | 0,284 |

## V. CONCLUSION

This study conducts a techno-economic analysis of a hybrid renewable energy system for productive activities in the shrimp farming industry in isolated areas in Indonesia, with a case study to meet the electricity needs of the shrimp farming industry on Bawean Island. HOMER software is used to optimize the design of the hybrid renewable energy system and provide an optimal hybrid power system configuration. Moreover, Bawean Island can no longer meet the electricity demand (many unserved customers need it), and a renewable energy system is needed.

This study conducts the design of a hybrid renewable energy system (HRES) using a Solar Power Plant (PV SYSTEM), Wind Power Plant (WIND TURBINE SYSTEM), BESS, Grid, and Converter. The potential for solar and wind radiation on Bawean Island is very suitable for use as a renewable energy source. Furthermore, simulations using HOMER software are carried out based on two configurations. Configuration 1 using PV SYSTEM, WIND TURBINE SYSTEM, GRID, and BESS utilizes PV SYSTEM as much as 8.9 MW, with 2 WIND TURBINE SYSTEM units and 3 BESS units, getting an LCOE value of 0.137 $ / kWh. The simulation results of configuration 1 show the performance of the PV SYSTEM module, an installed capacity of 8,933 kW and annual production reaching 13,841,249 kWh and wind performance of 4,839,321 kWh, with an energy cost (LCOE) of $ 0.0442 per kWh. Configuration 2 (PV SYSTEM, GRID, BESS) produces PV SYSTEM performance output with an installed capacity of 7,027 kW and a total annual production of 10,888,761 kWh / year. Thus, configuration 2 utilizes PV SYSTEM as much as 7 MW and 7 BESS units, getting an LCOE result of 0.284 $ / kWh. The comparison of total cost for each configuration based on LCOE ($/kWh) for Grid configuration is 0.187 $/kWh, Configuration 1 (PV SYSTEM, WIND TURBINE SYSTEM, BESS, GRID) is 0.137 $/kWh, and Configuration 2 (PV SYSTEM, BESS, GRID) is 0.284 $/kWh. Thus, configuration 1 (PV SYSTEM, WIND TURBINE SYSTEM, BESS, GRID) becomes the cheapest alternative.

Furthermore, considering the 2021-2030 RUPTL on the planning of PV SYSTEM development on Bawean Island and the excellent potential for solar and wind radiation on Bawean Island, it was found that configuration 1 (PV SYSTEM/WIND

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TURBINE SYSTEM/BESS/GRID) is the best alternative solution for planning the design of a renewable energy system aimed at meeting the electricity needs of the shrimp farming industry on Bawean Island. From an economic perspective, this project is profitable with an IRR of 77%, ROI of 93%, and a payback period of only 1.6 years, indicating the potential for fast and efficient returns. Based on these results, this study has implemented HRES in isolated areas for the productive sector so that the resulting electrification can potentially improve the population's welfare.

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