

## Design and efficiency optimization of off-grid solar-wind hybrid power systems in Bahuluang tourism village

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### Abstract

Access to reliable and sustainable energy remains a critical challenge in remote regions, limiting socio-economic growth and the development of tourism-based communities. In line with Indonesia's Net Zero Emissions (NZE) targets and national energy equity initiatives, this study explores the planning and efficiency optimization of a Hybrid Renewable Energy System (HRES) for Bahuluang Tourism Village. The proposed off-grid system integrates wind turbines, solar Photovoltaic (PV) panels, and battery storage to minimize fossil fuel dependence and environmental impact. Using literature review and simulation-based analysis with HOMER software, the study identifies an optimal configuration comprising 172.77 kW of solar PV, 36.82 kW of wind turbines, 98 batteries (1.2 kWh each), and a 50-kW inverter. The system generates approximately 209,851 kWh annually—82.4% from wind and 17.6% from solar—efficiently meeting the local demand of 424.1 kWh per day. This hybrid system supports sustainable energy access, reduces carbon emissions, and promotes the energy transition in line with Indonesia's clean energy goals.

### Keywords:

Hybrid power plant, new renewable energy, net zero emission, Bahuluang Tourism Village.

## 1 Introduction

Electricity demand continues to increase globally, making it a fundamental necessity in modern life. Beyond fulfilling basic consumption needs, access to electricity plays a critical role in accelerating regional economic growth and enhancing community welfare [1], [2]. In response, the Indonesian government has prioritized equitable energy distribution by ensuring the availability of sufficient, reliable, and affordable electricity across all regions [3].

According to the 2019 Indonesia Energy Outlook (OEI), the country's petroleum reserves declined to 7.51 billion barrels in 2018—a 0.27% decrease compared to 2017—highlighting the urgency of transitioning from fossil fuels to more sustainable alternatives [4],[5]. Indonesia is endowed with abundant and diverse New and Renewable Energy (NRE) resources, including solar, wind, hydro, and biomass [6]. Despite this potential, the development and utilization of NRE remain limited due to various challenges, particularly the high initial investment costs and technical constraints

in deployment [3],[9]. Overcoming these barriers is essential to support the national energy transition strategy and achieve long-term energy resilience [10].

Indonesia, as one of the world's largest archipelagic nations, consists of 17,491 officially verified islands as of 2019 (Kemenko Marves) [11]. Among these is Bahuluang Island, located in Bontosikuyu District, Selayar Islands Regency, South Sulawesi. Selayar Islands Regency lies at the southernmost tip of South Sulawesi Province and comprises a cluster of islands, with Selayar Island as the main landmass. Bahuluang Island, situated at coordinates 6°28'49.449"S, 120°25'39.645"E [12], features an open topography dominated by grasslands and savannas. This geographical structure, combined with its coastal positioning, makes the island consistently exposed to both west and east winds throughout the year. According to data from the Mining and Energy Office of Selayar Regency, the average annual wind speed suitable for energy generation is approximately 7.89 m/s. In addition, solar radiation data from the Solar and Wind Energy Resource Assessment indicate an average solar irradiance of 6 kWh/m<sup>2</sup>/day on the island, further highlighting its strong potential for renewable energy development [13].

The amount of energy potential in Bahuluang Tourism Village has not been properly utilized for the energy needs of the community. Based on data from literature studies, shows that people's needs for the use of electrical energy are quite high. This results in people still using diesel electricity which is less environmentally friendly and causes carbon dioxide pollution [14].

Despite the considerable wind and solar energy potential in Bahuluang Tourism Village, the local community remains heavily reliant on diesel generators, which are environmentally harmful and economically inefficient. The absence of an optimized renewable energy system not only contributes to ongoing carbon emissions but also limits opportunities for sustainable development in the region [15]. This gap between renewable energy potential and actual energy utilization presents a critical challenge that must be addressed through efficient NRE planning and system design tailored to local conditions.

Hybrid power generation systems are increasingly recognized as a vital component in the future of sustainable electricity supply, particularly due to their ability to integrate multiple renewable energy sources—such as solar and wind—without emitting air pollutants. The incorporation of energy storage systems, load control mechanisms, and Energy Management Systems (EMS) significantly enhances their operational efficiency, reliability, and adaptability in diverse environmental conditions [16]. Such systems are especially well-suited for remote and island communities with limited access to centralized power grids. In this context, the present study emphasizes the efficiency planning of NRE in Bahuluang Tourism Village through the deployment of a hybrid power plant that combines wind turbines and Photovoltaic (PV) panels [17]. The implementation of this system is intended to reduce dependence on fossil fuels, lower carbon dioxide emissions, and support Indonesia's commitment to achieving its Net Zero Emissions (NZE) targets [18].

## 2 Literature review

### 2.1 Energy potential in Bahuluang Island

South Sulawesi Province geographically covers coastal and island areas, highlands, and lowlands. The area of South Sulawesi is 46,717.48 km<sup>2</sup> with a population density of 175.84 people/km<sup>2</sup> spread across 24 regencies/cities, namely 21 regencies and 3 municipalities, 304 sub-districts, and 2,953 villages. Located at the crossroads of international transportation routes, this province has 295 islands and 190 of them already have names (Fig. 1).'

Karang Bahuluang Island (Van Ophujsen spelling: Baeoelawang) is a small island located southwest of Salazar Island in the Selayar Islands group, Flores Sea waters and administratively included around Bahuluang Village, Bontosikuyu District, Selayar Islands Regency, South Sulawesi, Indonesia.



Fig. 1. Bahuluang coral island (Google Maps)

Astronomically, the island which has white sand is located at the coordinate point  $6^{\circ}28'49.449''S$ ,  $120^{\circ}25'39.645''E$  [5][13]. According to data from Wonderful Selayar the population on this island will be around 326 people in 2022 and most of the residents make a living as fishermen. The first inhabitants of this island came from the Seram tribe, in Maluku Province. The name "Bahuluang" was taken from the name of a Seram resident named Bahuluang [12].

## 2.2 Energy potential in Bahuluang Tourism Village

The sun serves as a vast and continuous source of renewable energy, capable of being converted into heat or electricity without combustion, thereby eliminating greenhouse gas emissions. Solar energy is increasingly recognized as an environmentally friendly alternative to conventional fossil fuels due to its clean and sustainable nature [19].

In the Indonesian context, solar irradiation data collected from 18 locations indicate an average solar radiation of approximately  $4.8 \text{ kWh/m}^2/\text{day}$ , with  $4.5 \text{ kWh/m}^2/\text{day}$  in the western region and  $5.1 \text{ kWh/m}^2/\text{day}$  in the eastern region, and a monthly variation of around 9% [12]. Specifically, Bahuluang Island recorded an average solar radiation of  $5.99 \text{ kWh/m}^2/\text{day}$  and a daily mean temperature of  $27.62^{\circ}\text{C}$  in 2020, based on NASA data. These figures confirm the island's high potential for harnessing both solar and wind energy as key components of a renewable energy strategy.

Meanwhile, wind energy in Bahuluang Village also holds significant potential as an alternative energy source. According to data from the Energy and Mineral Resources Office (ESDM) of Selayar Regency, monthly wind speeds vary throughout the year, with the highest recorded in August at  $12.96 \text{ m/s}$  and the lowest at  $3.76 \text{ m/s}$ . This wind potential can be effectively utilized to drive wind turbines to generate electricity [12].

In Bahuluang Tourism Village, electrical energy is primarily utilized through solar thermal systems for cooking (solar stoves), drying agricultural products (such as those from plantations, fisheries, forestry, and food crops), and heating water. Solar PV energy is employed to supply electricity for various applications, including water pumps, televisions, telecommunications, and refrigerators—particularly in the community health center (Puskesmas)—with a total installed capacity of approximately 6 MW [8]. The main components of the Solar Energy System

Framework (SESF) include photovoltaic cells (which convert sunlight into electricity), balancing systems, energy storage units (batteries), and auxiliary components such as inverters for water pumps, central control systems, and hybrid integration technologies [20].

## 2.3 Hybrid power plant architecture

The integration of wind energy sources and solar cells for power generation is essential to reduce environmental planning due to CO pollutants [a]. This hybrid power plant combines several NRE sources, such as wind and solar energy. Hybrid power generation in a system combining generating sources. The hybrid power generation model combines renewable energy, thus keeping environmental pollution at bay [21].

As show in Fig. 2, the components in a hybrid power plant consist of solar panels, wind turbines, inverters, batteries, and several other supporting components. The combination of wind and solar energy produces clean and environmentally friendly energy. The electrical energy generated can be stored in the battery as a backup when the weather is not very good. The energy produced by the plant is in the form of dc electricity, so an inverter is needed to convert it into ac electricity so that it can be used for various daily electrical equipment [22].

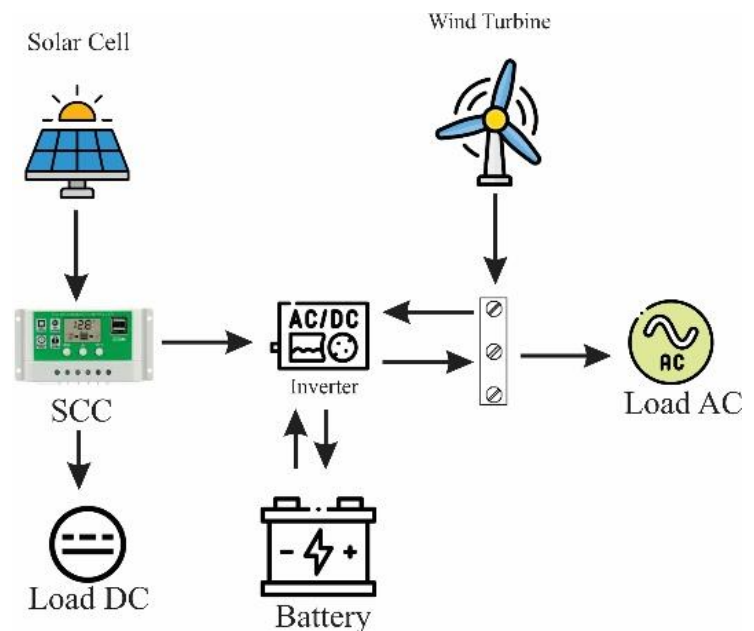


Fig. 2. Hybrid power plant architecture

## 2.4 PV panel planning

In a solar module, there are photovoltaic cells that are where the photovoltaic effect occurs. If several solar modules are assembled, a system called a solar power plant will be formed. The quality of a solar module can be judged based on its efficiency in converting sunlight radiation into dc electricity. Solar modules that have higher efficiency will produce more electrical power than solar modules that have lower efficiency for the same module area [11].

To collect a photon current, metal contacts are provided on both sides of the junction to collect the electric current induced by the photons impinging on one side. Making foil contacts (solder) are provided above the bottom surface (dark) and on one of the edges of the upper surface (illuminated). A thin mesh of conductors on the remaining upper surface collects current and lets light in [23].

The efficiency of solar modules, among others, depends on the material of the photovoltaic cell and its production process. In general, photovoltaic cells are made of crystalline and non-crystalline (thin film) type materials. The crystalline type is divided into the mono-crystalline type and poly-crystalline type (Fig. 3), with a conversion efficiency of about 12-20%. Here's a comparison between poly-crystalline and mono-crystalline [24].

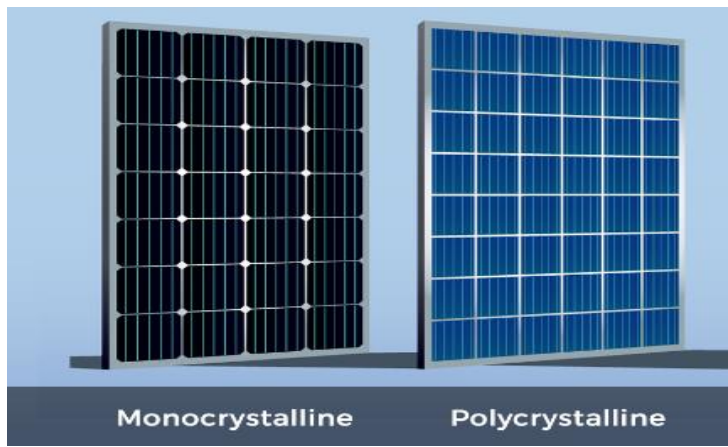


Fig. 3. Types of solar panels

## 2.5 Wind power plant planning

A wind Power Plant often also referred to as a wind turbine (Fig. 4) is a plant that utilizes wind kinetic energy that enters the effective area of the turbine to rotate the propeller/windmill, then this rotary energy is forwarded to the generator to generate electrical energy. Current wind turbine technology can convert wind motion energy into electrical energy with an average efficiency of 40%. This 40% efficiency is because there will always be kinetic energy left in the wind. After all, the wind coming out of the turbine cannot have a speed equal to zero [25].



Fig. 4. Wind turbine vertical

## 3 Method

### 3.1 Research data

In this study, the planning of a NRE system was conducted for Bahuluang Tourism Village, Selayar Regency, by implementing an off-grid Hybrid Power Plant to meet the electricity demands of various community activities. The proposed hybrid system specifically integrates solar photovoltaic and wind energy, considering the significant potential of these resources in the area. Research data were obtained through a literature review from various relevant sources and were used as the basis for simulating the optimization of the hybrid power plant configuration.

### 3.2 Methodological framework

This study adopts a simulation-based planning approach to design a Hybrid Renewable Energy System (HRES) for Bahuluang Tourism Village, Selayar Islands Regency. The methodological framework consists of three main phases,

#### 1. Preliminary data collection

Data were gathered through field observations, measurements, and literature review to assess current electricity consumption patterns and the management of existing renewable energy infrastructure. Emphasis was placed on understanding the energy

demands of key facilities, including households, water pumps, and the health centre (Puskesmas).

#### 2. Technical component assessment

Specifications and lifetime data of critical system components—including photovoltaic modules, wind turbines, battery storage, and inverters—were collected to support accurate modelling and cost estimation. This information serves as a foundation for defining system parameters in the simulation process.

#### 3. System design and simulation

Various hybrid configurations were simulated by integrating solar and wind energy sources with battery storage. The simulation aimed to identify the most efficient and cost-effective system design, based on technical feasibility, total net present cost, renewable fraction, and carbon emission reduction.

### 3.3 Hybrid power plant plan

Analysis of the operating performance of the hybrid power plant system of Bahuluang Tourism Village. The generation system that has been designed can be seen in Fig. 5.

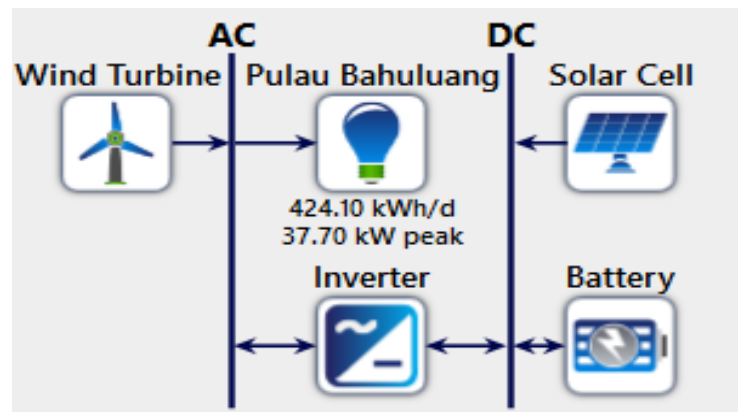


Fig. 5. Wiring diagram simulation of NRE power plant Bahuluang Tourism Village

From Fig. 5 it is explained that the main components of a hybrid generation system are wind turbines, solar PV, batteries, inverters, and the load itself. Wind turbines and solar PV generation systems produce dc electricity, so an inverter is needed to convert it into dc voltage before being channeled to the load to be used.

## 4 Results and discussion

### 4.1 Total load

Bahuluang Tourism Village has several infrastructures such as people's houses, mosques, elementary school buildings, village office buildings, PUSKESMAS buildings, and power plant facilities. The facility requires electricity to be used daily to support activities on the island. The total load can be seen in Table 1.

Table 1. Assumptions of the overall amount of load to be served

No	Types of Loading	Power (W)
1	Resident's Houses (80 Houses)	36.800
2	Generating Facilities	304
3	Houses of Worship (Mosques)	470
4	Elementary School Building	495
5	Village office building	456
6	Auxiliary Health Centre Building	368
Total		38,890 W

So the maximum power consumption obtained on all loads on Bahuluang Island through this load study amounted to 38,890 Watts or 38,890 kW[12]. Determining the total load requirement of Bahuluang Tourism Village is the first step in designing a hybrid electric generation system. In the hybrid system designed, the solar power plant supplies the entire energy during the day. The amount of load energy that will be supplied by the banker can be seen in Table 2 and Fig. 6.

Table 2. Load profile in Bahuluang tourism village

Time	Electrical Load
00.00-01.00	18.967
01.00-02.00	18.967
02.00-03.00	18.967
03.00-04.00	18.967
04.00-05.00	18.967
05.00-06.00	18.967
06.00-07.00	18.967
07.00-08.00	10.668
08.00-09.00	10.668
09.00-10.00	10.668
10.00-11.00	10.668
11.00-12.00	10.668
12.00-13.00	10.668
13.00-14.00	10.738
14.00-15.00	9.352
15.00-16.00	9.352
16.00-17.00	9.422
17.00-18.00	9.352
18.00-19.00	9.352
19.00-20.00	37.696
20.00-21.00	37.696
21.00-22.00	37.696
22.00-23.00	37.696
23.00-00.00	18.967
<b>Total Load</b>	<b>424,1</b>

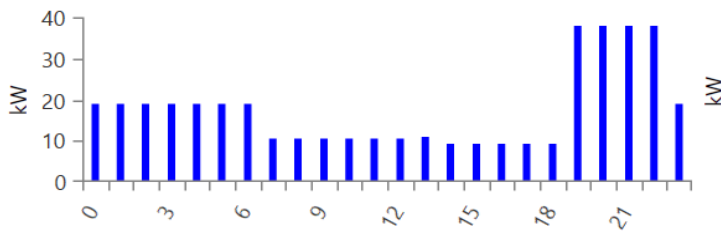


Fig. 6. Load per day graph

The assumption of losses in the system is 15% because all system components used are new. The total required system energy is obtained Eqs. (1) and (2).

$$\text{Total Energy} = \text{Load} + \text{System Losses} \quad (1)$$

$$\begin{aligned} \text{Total Energy} &= \text{Load}(15 \times \text{Load}) \quad (2) \\ &= 487,715 \text{ Wh} \end{aligned}$$

#### 4.2 Wind energy potential

The average wind speeds each month in Selayar Islands Regency is not much different from Bahuluang Island, so to analyze the potential of wind energy on Bahuluang Island did not have enough time for six months to get the average wind speed each year, therefore researchers took data from the ESDM Office of Selayar Regency. as reference material in the data processing. The average monthly wind speed on Bahuluang Island can be seen in Table 3 and Fig. 7.

Table 3. Wind speed

Month	Wind Speed (m/s)	Month	Wind Speed (m/s)
January	9,28	July	11,05
February	5,05	August	12,96
March	3,76	September	6,69
Apryl	3,93	Oktober	7,52
May	5,44	November	8,96
Juny	9,39	December	10,34

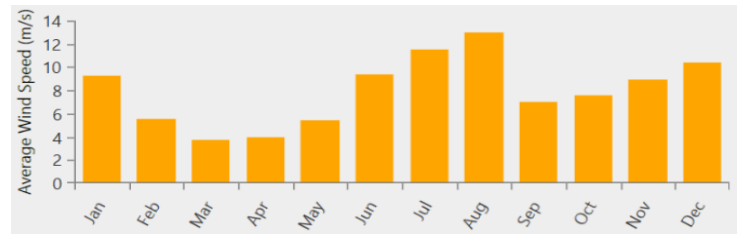


Fig. 7. Graph of wind energy potential on Bahuluang Island

#### 4.3 Solar energy potential

Data collection of solar radiation intensity can be done by taking data directly at the location or by using data provided by NASA. In this study, researchers took data through data provided by NASA. To get solar radiation intensity data on simulation software simply enter the coordinates of Bahuluang island, where the coordinate points are: 6° 28' 49.449" LS and 120° 25' 39.645" E. Based on this, the intensity of solar radiation reaches an average of 5.99 kWh // h every year with the average every month can be seen in Table 4 and Fig. 8.

Table 4. Solar energy potential

Month	Clearness Index	Daily Radiation(kWh/m <sup>2</sup> /h)
Jan	0.487	5.2
Feb	0.499	5.37
Mar	0.582	6.12
Apr	0.594	5.84
May	0.632	5.7
Jun	0.632	5.41
Jul	0.654	5.71
Aug	0.686	6.48
Sep	0.704	7.18
Oct	0.673	7.14
Nov	0.602	6.41
Dec	0.504	5.35



Fig. 8. Graphic of solar potential on Bahuluang Island

#### 4.4 PV module capacity calculation

The power capacity of solar cell modules can be determined by considering several factors, including the system's energy demand, solar insolation, and adjustment factors. The estimated energy requirement for the system, as previously calculated, is 424.1 kWh In Table 2. By utilizing the lowest recorded solar insolation values, it is ensured that solar energy can meet the load demand under all conditions.

The minimum recorded solar radiation is 52 W/m<sup>2</sup>/day. To obtain the solar insolation value, the radiation figure is divided by the average duration of solar irradiation per day, assumed to be 8 hours, resulting in 6.5 W/m<sup>2</sup>. An Adjustment Factor (AF) of 1.1 is applied, which is typical for most solar power installations (Mark Hankins, 1991, Small Solar Electric Systems for Africa, p. 68). Based on these parameters, the power capacity of the required solar module is then calculated using Eqs. (3) and (4). The amount of solar module power capacity is 72,743.9-watt Peak.

$$\begin{aligned}
 PV \text{ Capacity} &= \frac{\text{Total Load}}{\text{Solar Insolation}} \times AF & (3) \\
 &= \frac{390,172}{5.9} \times 1,1 \\
 &= 72,743.9 \text{ Wp}
 \end{aligned}$$

The amount of solar module power capacity is 72,743.9-watt Peak.

$$\begin{aligned}
 PV &= \frac{PV \text{ Capacity}}{\text{Spesifications of PV Used}} & (4) \\
 &= \frac{72,743.9}{320} \\
 &= 227.3 \text{ pcs} \\
 &= 228 \text{ pcs}
 \end{aligned}$$

#### 4.5 Battery capacity calculation

The battery used to supply a load of 424,100 watts using a 12 V 105 Ah battery is obtained by Eq. (5). The battery is to supply the load for one day if the PV or wind turbine is not functioning optimally.

$$\begin{aligned}
 \text{Battery} &= \frac{\text{Total watt hour/day}}{(0.85 \times 0.6 \times \text{Battery Voltage})} & (5) \\
 &= \frac{424,100}{12 \times 0.85 \times 0.6} \\
 &= 69,297 \text{ Ah} \\
 &= \frac{69,297}{105} \\
 &= 695 \text{ pcs}
 \end{aligned}$$

#### 4.6 Calculation of wind turbine capacity

Wind turbines used to supply loads that are about 40,000 Watts are, so the calculation of the wind turbine capacity is obtained by Eq. (6). So based on the calculation of the need for this system with a 3.3 kW density turbine is 25 pcs.

$$\begin{aligned}
 \text{Wind Turbine} &= \frac{\text{Total Load}}{\text{Turbin} \times \text{Efisiensi}} & (6) \\
 &= \frac{40,000 \text{ Watt}}{3,300 \text{ Watt} \times 0,5} \\
 &= 24.2 \text{ pcs} \\
 &= 25
 \end{aligned}$$

#### 4.7 Results of hybrid plant planning simulation

Based on the data that has been entered, some optimal results are obtained, and the best is in the first condition. The simulations that have been carried out obtained the best results in system modeling that will be applied to hybrid power generation planning. Where the percentage of plant composition and the number of components to be planned are, solar panels amounting to 158.245 kW, and wind turbines amounting to 38.941 kW. 1.2 kWh battery as many as 96 pieces, 12 Volt Inverter 50 kW.

##### 4.7.1 Annual electricity production

The resulting electricity generation and consumption data are presented in Table 5 and Table 6, respectively. These data provide insights into the performance of the HRES and the balance between energy supply and demand in Bahuluang Tourism Village.

Table 5. Annual electricity production

Production	Total (kWh/year)	Percentase (%)
Wind turbin	36,815	17.6
PV panels	172,766	82.4
Total	209,851	100

As shown in Table 5, the total annual electricity production reaches 209,581 kWh. PV panels contribute the largest share of electricity generation, accounting for 82.4% of the total, while wind turbines contribute 17.6%. This indicates the dominance of solar energy in the hybrid system due to the high solar insolation levels on the island.

Table 6. Annual electricity consumption

Consumption	Sum (kWh/year)	Percentase (%)
AC load	154.685	100
DC load	0	0
Total	154.685	100

Table 6 illustrates the annual electricity consumption, which is entirely attributed to AC loads with a total demand of 154,685 kWh/year. No DC load is utilized in the current configuration, simplifying system design and inverter requirements. Monthly electricity production data are illustrated in the corresponding figure above. Fig. 9 shows the average monthly electricity generation, highlighting seasonal variations.

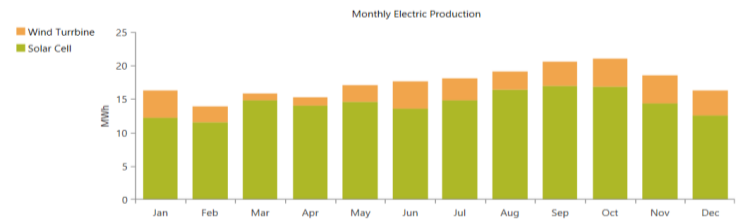


Fig. 9. Graphic of average electricity production

##### 4.7.2 PV panel planning

Based on the simulation results, the most optimal system configuration includes a planned solar panel capacity of 101 kW. Using Canadian Solar PV modules rated at 320 Wp each, a total of 319 modules are required. The system achieves a capacity factor of 19.5%, reflecting the average daily power output relative to the rated capacity. Detailed performance data of the solar panels are presented in Table 7, while the PV penetration profile is illustrated in Fig. 10.

Table 7. Data on electrical energy generated by solar panels

Quantity	Value	Unit
Rated Capacity	101	kW
Mean output	19,7	kW
Mean Output/day	473	kWh/d
Capacity Factor	19,5	%
Maximum Output	88,4	kW
Operation Hours	4.380	Hour/Year

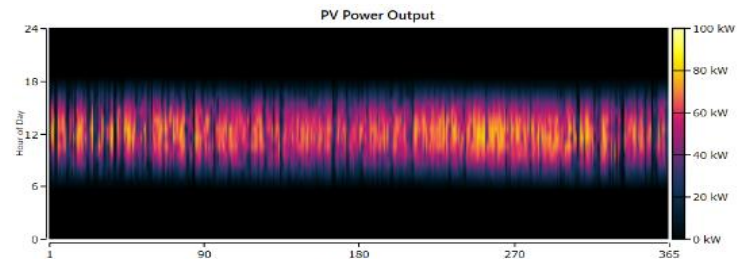


Fig. 10. PV penetration

As shown in Fig. 10, the PV system consistently generates electricity from approximately 09:00 to 16:00 throughout the year. This stable solar generation window contributes significantly to the total energy production, making PV panels a reliable and dominant source of renewable energy for the system. The high penetration rate of solar energy confirms its potential to meet daily electricity demands in Bahuluang Tourism Village under varying environmental conditions.

### 4.7.3 Wind turbines

According to the simulation results, the wind turbine system is designed to generate a total rated power of 13.2 kW under the optimal system configuration. This is achieved using four AWS wind turbines, each rated at 3.3 kW. The system demonstrates a capacity factor of 31.8%, which is notably higher than that of the solar PV system. This is primarily due to the consistent wind availability throughout the year, allowing for more stable and continuous power generation. The detailed simulation data for the wind turbine system are presented in Table 8, and the wind energy penetration profile is illustrated in Fig. 11.

Table 8. Simulated data

Quantity	Value	Unit
Total Rated Capacity	13.2	kW
Mean Output	4.20	kW
Capacity Factor	31.8	%
Maximum output	18	kW
Wind Penetration	23.8	%
Operating hours	6,798	Hour/year
Total Production	36,815	kWh/year

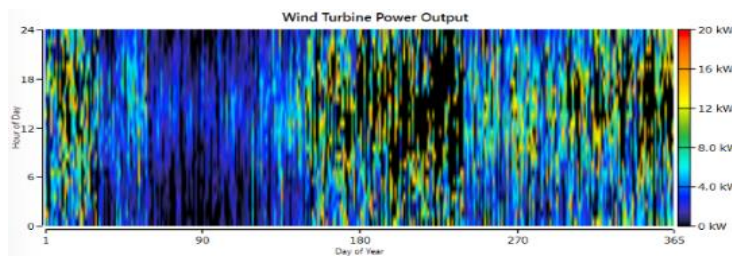


Fig. 11 Wind turbine penetration

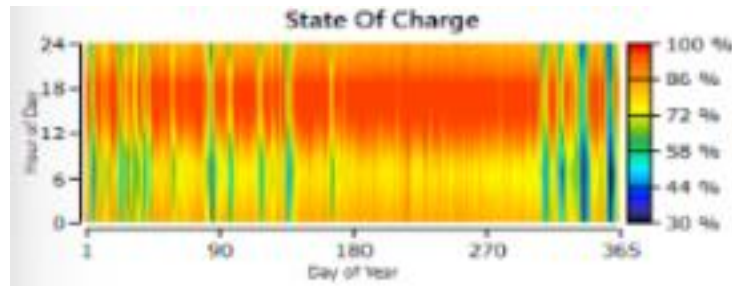


Fig. 12. State of charge battery

### 4.7.5 Inverter capacity

The inverter specifications must be compatible with the Battery Charge Regulator (BCR) to ensure proper system operation and power delivery. The inverter is responsible for converting the stored DC power into AC electricity with an output voltage of 220 V, suitable for end-user loads. Based on the simulation results, the system requires an inverter with a capacity of 50 kW. Table 10. Inverter specifications.

Quantity	Value	Unit
Inverter capacity	43.4	kW
Mean Output	13.7	kW
Minimum Output	0.0	kW
Maximum Output	37.7	kW
Capacity Factor	31.6	kW
Operating hours	8,077	hour/year
Losses	3,717	kWh/year
Output Energy	120,185	kWh/year
Input Energy	23,902	kWh/year

A Schneider-brand inverter is selected due to its proven reliability and efficiency in hybrid renewable energy systems integrating both solar panels and wind turbines. Detailed technical

As shown in Fig. 11, wind turbines contribute a substantial portion of the total electricity supply, with consistent output throughout the year. This continuous generation complements the solar PV system, especially during periods of low solar irradiance, and enhances the overall reliability, stability, and sustainability of the hybrid renewable energy system

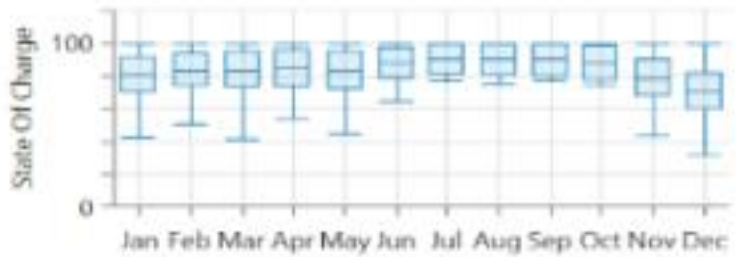
### 4.7.4 Battery capacity

Based on the simulation results, the system utilizes 96 generic lead-acid batteries, each with a nominal voltage of 12 V and a storage capacity of 1 kWh. These batteries are integrated into the hybrid renewable energy system, operating in conjunction with both the solar PV and wind turbine subsystems. The battery configuration is arranged in parallel strings to match the required bus voltage and optimize energy storage and delivery performance. Detailed specifications and pricing information are provided in the appendix. The key performance data for the battery storage system are presented in Table 9, while the battery State of Charge (SOC) profile is illustrated in Fig. 12.

Table 9. Battery specifications

Quantity	Value	Unit
Number of Batteries	96	Unit
String Size	1.00	-
Strings in Parallel	96	Strings
Bus Voltage	12	Volt
Lifetime Throughput	1,472,635	kWh
Losses	2,987	kWh/year

Fig. 12 shows the SOC profile of the battery bank throughout the year. The SOC remains within optimal operating limits, indicating the battery system's ability to store and discharge energy efficiently in response to fluctuations in generation and load demand.



specifications and pricing are provided in the appendix. The simulated performance data of the inverter are presented in Table 10.

### 4.7.6 Design cost details

Based on the table it is known that the cost can be summed up in table 11. The cost per kWh using a hybrid generation system is around Rp. 1,514.88 per kWh. The investment cost of each component can be seen in Fig. 13.

Table 11. Details of power plant planning costs

Total NPC	Rp 3,011,875,091
Levelized COE	Rp. 1,506.17
Operating Cost	Rp. 100,848,200

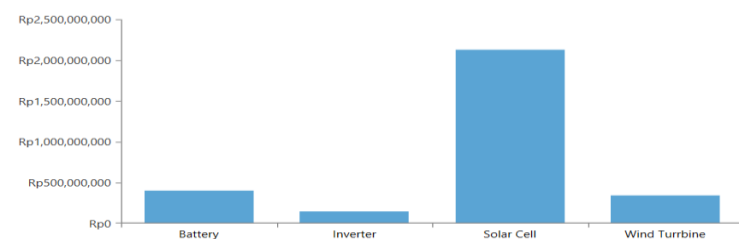


Fig. 13. Investment cost for each component

#### 4.7.7 Financial analysis

Based on the simulation results, the total energy consumption per year is 154,769 kWh/year so the cost per kWh can be determined based on annual expenditure. The simulation results obtained a total expenditure for 25 years of Rp. 3,011,874,478.89 can be obtained by Eq. (7). So, the annual investment needed for the construction of a hybrid power plant in Bahuluang Tourism Village is Rp. 120,474,979/year

$$\begin{aligned} \text{Expenditures per year} &= \frac{\text{Total Investment Cost}}{\text{Investment Duration}} & (7) \\ &= \frac{3,011,874,478.89}{25} \\ &= \text{Rp. } 120,474,979/\text{year} \end{aligned}$$

#### 5 Conclusion

The results of this study highlight the viability of a hybrid renewable energy system for sustainable energy provision in Bahuluang Tourism Village. The village's total electricity demand was calculated at 424.1 kWh per day. The optimized system, integrating 172.77 kW of solar PV and 36.82 kW of wind turbines supported by 98 battery units (1.2 kWh each), achieves an annual electricity production of 209,851 kWh. The investment cost for constructing the hybrid energy facility is estimated at IDR 3,011,875,091, with an annual operating cost of IDR 100,848,200 and a resulting electricity price of IDR 1,506.17/kWh. This design not only meets local energy needs efficiently but also supports broader national targets for energy sustainability and carbon emission reduction.

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