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Potential of Wind Power Plant Development at Bohay Beach, Paiton, Probolinggo Regency

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Abstract

This research is only to determine the potential of wind on BohayPaiton Beach, Probolinggo Regency as alternative electrical energy. The large potential of wind and electrical power generated at BohayPaiton beach is a research object. Electrical alternative energy can overcome limitations and help with additional lighting at BohayPaiton beach which has not been provided. The method used is a survey method and the Zephyrus WindMeter application on a smartphone. The survey was carried out directly at BohayPaiton Beach at 07.00 – 17.00 WIB using the Zephyrus WindMeter application on a smartphone to collect wind speed data. Data collection was carried out at 5 points as a reference by taking measurements 3 times at each reference point. Several journal literature studies show that wind has the potential to be used as alternative energy by creating effective wind power plants. Based on the calculation results, the data shows that BohayPaiton Beach has an average maximum speed of 2.5 m/s and the electrical power generated from the calculation is 28.7 Watts, so other alternatives are needed to overcome low wind speeds and design power plants.

Keywords: alternative electrical energy, wind speed, electrical power, generator design

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1. Introduction

The Development Potential of Wind Energy in Indonesia remains relatively low despite its vast untapped resources [1]. Wind is a form of kinetic energy that moves from high-pressure to low-pressure regions. Probolinggo Regency is known for its varying wind speeds, particularly the Gending wind [2]. Wind velocity can be measured using an anemometer, a device commonly utilized by meteorological agencies to quantify wind speed. The cup anemometer, consisting of three or four hemispherical cups mounted horizontally, measures wind speed based on the rotational speed of the cups relative to time. The rotation is converted into readable wind speed values. Additionally, portable tools such as the Zephyrus WindMeter smartphone application are increasingly being used by researchers and the public to assess wind potential in various regions. This application offers a practical and accessible method for wind speed measurement [3].

The Gending wind represents a significant renewable energy resource for Probolinggo Regency, complementing other wind potentials such as coastal and inland winds that are yet to be fully harnessed for electricity generation. Besides its renewable energy potential, Probolinggo is also a prominent tourist destination, home to attractions like Bohay Beach. The region's geographical advantages include expansive coastlines and mountain ranges, which are actively being developed for tourism [4-7]. However, electricity scarcity in coastal areas remains a pressing issue. Access to reliable electricity is critical for lighting, local economic activities, and infrastructure development. Establishing wind power plants in these regions could mitigate the electricity shortage by utilizing wind energy as an alternative power source.

Wind Power Plants (WPPs) generate electricity by converting wind energy into mechanical power using turbines. As wind is an abundant and sustainable resource, wind energy has emerged as one of the fastest-growing renewable energy sectors globally. Wind power generation is increasingly recognized for its feasibility and efficiency. Indonesia's vast potential for expanding its renewable energy sector, particularly wind energy, where wind speeds average around 5 m/s, sufficient for small-to-medium-scale power generation [8]. Wind turbines effectively capture this kinetic energy, transforming it into useful electrical energy. Harnessing Bohay Beach's coastal wind potential through the development of wind power plants could provide an alternative source of electricity for Probolinggo, addressing energy access challenges in the region. This study aims to offer a practical solution by utilizing the marine wind potential of Bohay Beach, Paiton, for sustainable energy development [10-11].

2. Methods

2.1 Research Workflow Explanation

This research employs a survey-based method combined with digital wind speed measurement utilizing the Zephyrus WindMeter smartphone application. The field measurements were conducted directly at Bohay Beach, Paiton, Probolinggo Regency, on October 10, 2024. The Zephyrus WindMeter application was selected due to its practicality and accessibility in field data acquisition for wind speed measurements.

Data collection was performed by conducting repetitive measurements three times at five distinct reference points within the Bohay Beach area. To account for temporal variations in wind speed, measurements at each reference point were conducted at two-hour intervals. This approach was intended to ensure that variations in environmental conditions were adequately captured throughout the study period.

The wind power potential was calculated manually using standard wind power equations to estimate the available kinetic energy based on the measured wind speeds. The equipment and materials utilized during the research included a laptop, smartphone, scientific journals, reference books, and supporting stationery supplies to facilitate data recording and computation.

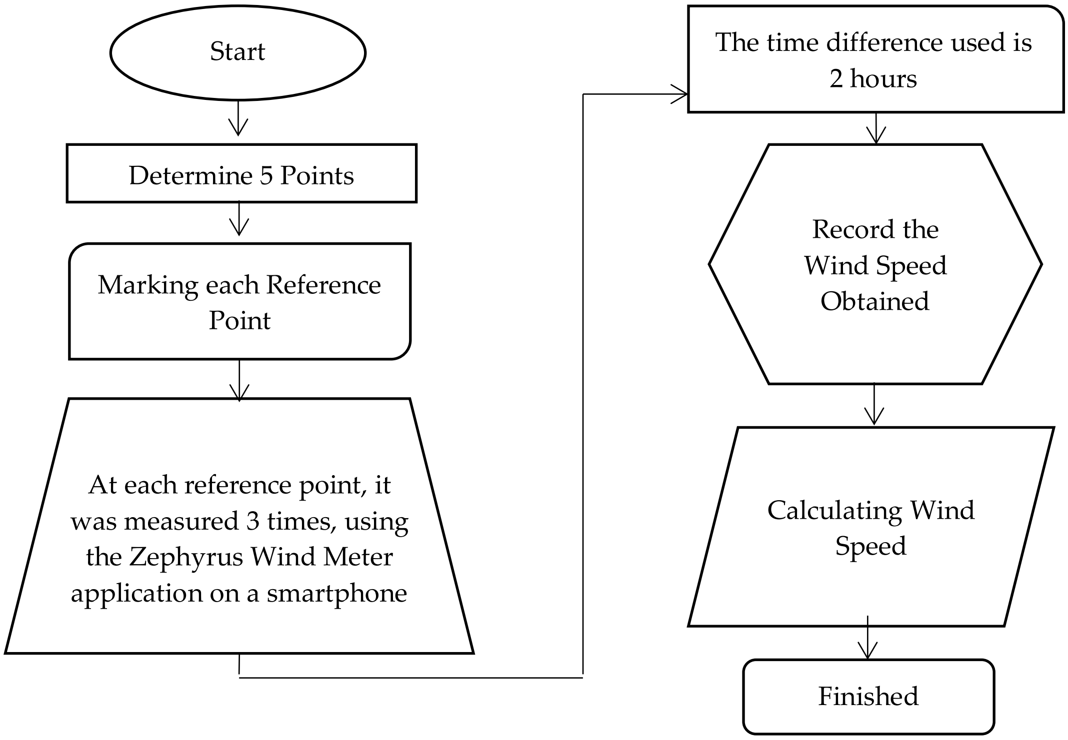

Figure 1. Research Flowchart

The research procedure for measuring wind energy potential at Bohay Beach, Paiton was conducted through a systematic workflow to ensure data accuracy and consistency. The following outlines each step of the process:

Start

The research activity commenced with a preparatory phase that involved checking all required tools and materials, such as the Zephyrus WindMeter application installed on a smartphone, data recording sheets, and site maps of Bohay Beach. Preliminary calibration and validation of the application were also ensured before field deployment.

Determine 5 Reference Points

Five strategic measurement points were selected across different zones of Bohay Beach to capture variations in wind flow patterns. These points were chosen based on geographic spread, proximity to open coastal areas, and potential exposure to prevailing winds.

Marking Each Reference Point

Each reference point was clearly marked and geo-tagged using GPS coordinates for accurate location identification. This marking ensured that repeated measurements could be conducted at precisely the same location, minimizing spatial discrepancies.

Measurement at Each Reference Point (3 Times)

At every designated reference point, wind speed measurements were conducted three times consecutively. This repetition was intended to reduce measurement errors and to obtain a reliable average reading for each point.

Utilizing Zephyrus WindMeter Application

All measurements were performed using the Zephyrus WindMeter application installed on a smartphone. The app leverages the phone's microphone to capture airflow sounds, which are then converted into wind speed readings using calibrated algorithms.

2-Hour Time Intervals Between Measurements

Measurements at each reference point were spaced two hours apart to observe wind speed fluctuations throughout the day. This temporal spacing allowed the research to capture potential variations in wind behavior due to environmental factors such as tides, temperature changes, and atmospheric pressure shifts.

Record the Wind Speed Obtained

All recorded wind speed data from each measurement session were meticulously documented in prepared data sheets, ensuring that every reading was timestamped and linked to its corresponding reference point.

Calculating Wind Power Potential

After data collection, the wind speed readings were processed using the standard wind power formula ($P = 0.5 * \varrho * A * V^3$), where ϱ is air density, A is the swept area of the turbine blade, and V is the wind velocity. This calculation was performed manually to estimate the potential wind energy available at each location [12].

Finish

The research process concluded after the completion of data analysis. The results were compiled for further discussion, leading to conclusions regarding the feasibility of wind power generation at Bohay Beach.

2.2 Research Location

The field study was conducted at Bohay Beach (Pantai Bohay), Paiton District, Probolinggo Regency, East Java, Indonesia. The precise location is situated at Jalan Raya Pantura, Dusun Pesisir, Bhinor Village, Paiton Sub-district, Probolinggo Regency, East Java, Postal Code 67291. Bohay Beach is geographically positioned along the northern coastal line of East Java, making it an ideal site for assessing coastal wind energy potential due to its open exposure to sea breezes and prevailing winds. The selection of this location was based on its strategic relevance for renewable energy exploration and the local community's need for alternative electricity solutions.

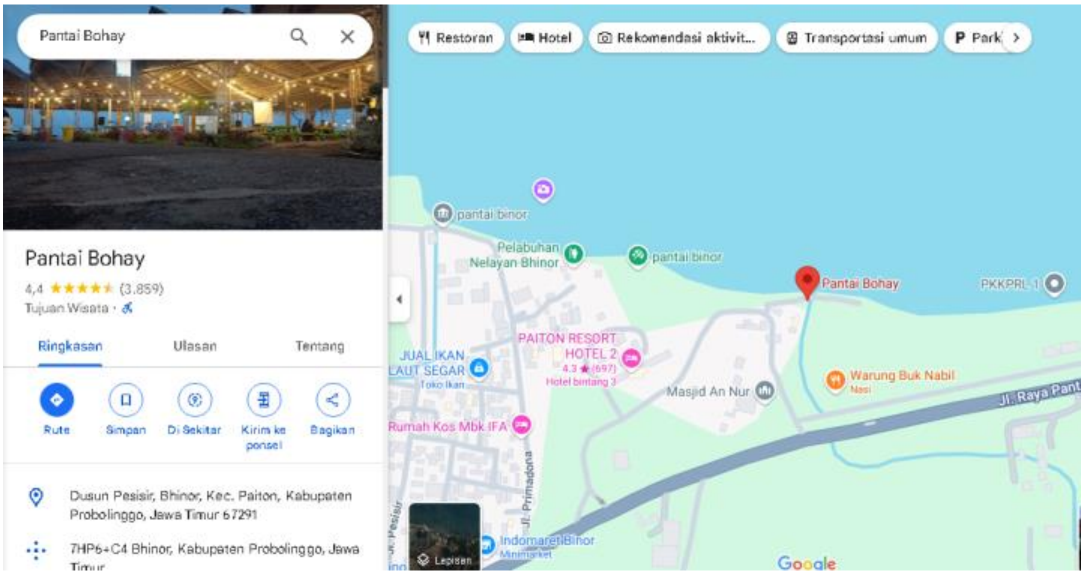

Figure 2. Research Location Map Visualization

3.Results and Discussion

3.1 Wind Speed Measurement

The field measurements were conducted on October 10, 2024, utilizing the Zephyrus WindMeter application installed on a smartphone as the primary tool for wind speed data collection. Measurements were carried out systematically at five distinct reference points across Bohay Beach, Paiton, Probolinggo Regency to capture spatial variations in wind velocity.At each reference point, wind speed was measured three times consecutively, with a two-hour interval between measurement sessions. This method was implemented to account for temporal fluctuations in wind speed throughout the day, ensuring a comprehensive and accurate dataset.

The repeated measurements at multiple points aimed to reduce potential errors, improve data reliability, and provide a more representative assessment of the area's wind energy potential. The collected wind speed data were then processed to calculate the corresponding wind power potential using standardized aerodynamic equations.Further analysis of the results revealed the distribution of wind speeds across different locations and time intervals, highlighting the dynamic characteristics of coastal wind patterns at Bohay Beach. This dataset serves as the foundation for evaluating the site's feasibility for small-scale wind energy harvesting.

Table 1. Wind Speed Measurement Data

Date	n	Location									
		Point 1		Point 2		Point 3		Point 4		Point 5	
		O'clock	V m/s)	O'clock	V m/s	O'clock	V m/s	O'clock	V m/s	O'clock	V m/s
October 10, 2024	1	08.01	0.1	08.01	0	08.01	0.1	08.01	0.2	08.01	0.1
	2	08.03	0.2	08.03	0	08.03	0.3	08.03	0.2	08.03	0
	3	08.06	0	08.06	0.2	08.06	0.2	08.06	0.3	08.06	0.2
	1	10.01	0.2	10.01	0.3	10.01	0.2	10.01	0	10.01	0.1
	2	10.03	0.3	10.03	0.2	10.03	0.2	10.03	0	10.03	0.2
	3	10.06	0.2	10.06	0.3	10.06	0	10.06	0	10.06	0.2
	1	12.01	0.5	12.01	0.4	12.01	0.6	12.01	0.7	12.01	0.5
	2	12.03	0.5	12.03	0.5	12.03	0.5	12.03	0.4	12.03	0.6
	3	12.06	0.4	12.06	0.3	12.06	0.6	12.06	0.5	12.06	0.4
	1	14.01	1.2	14.01	1.2	14.01	0.9	14.01	1.3	14.01	1.2
	2	14.03	1.3	14.03	1.0	14.03	0.6	14.03	1.2	14.03	1.0
	3	14.06	0.9	14.06	1.3	14.06	0.7	14.06	1.3	14.06	1.8
	1	16.01	0.9	16.01	1.3	16.01	1.1	16.01	1.1	16.01	0.9
	2	16.03	1.2	16.03	1.0	16.03	1.3	16.03	0.9	16.03	1.4
	3	16.06	1.3	16.06	1.5	16.06	1.5	16.06	1.0	16.06	1.3

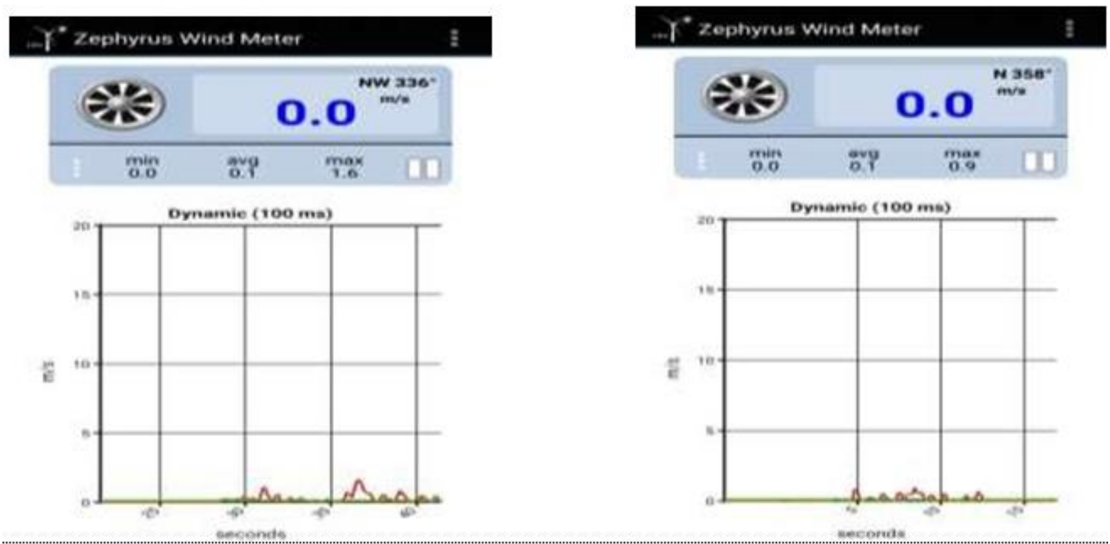

Figure 3. Graph at 08.01 WIB, Graph at 10.03 WIB

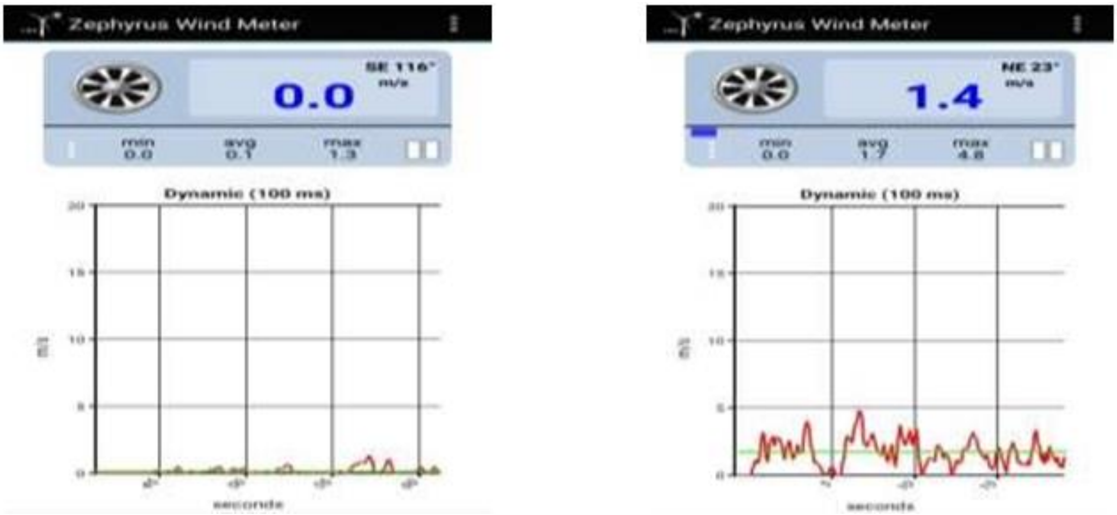

Figure 4. Graph at 12.06 WIB, Graph at 14.01 WIB

Figure 5. Wind speed graph at 16.01 WIB.

The wind speed graphs presented in this study were derived from measurement data collected using the Zephyrus WindMeter application, with observations conducted at two-hour intervals to obtain the maximum average wind speed at each reference point throughout the day. Figure 3 illustrates the wind speed distribution recorded at 08:01 AM (WIB), capturing the morning wind patterns as coastal air movements begin to develop. Subsequently, Figure 3 shows the wind speed measurements at 10:03 AM (WIB), indicating a noticeable increase in velocity due to intensified thermal activity. At midday, Figure 3 presents the wind profile at 12:06 PM (WIB), typically representing the peak period of wind intensity resulting from differential heating between land and sea surfaces. Moving into the afternoon, Figure 4 displays wind speed data recorded at 14:01 PM (WIB), reflecting stabilized atmospheric conditions with moderate wind flow. Finally, Figure 5 visualizes the wind behavior at 16:01 PM (WIB), highlighting the variations in wind patterns as solar radiation decreases towards sunset. These sequential graphical representations provide critical insights into the diurnal fluctuations of wind velocity at Bohay Beach, which are essential in evaluating the site's feasibility for wind power generation applications.

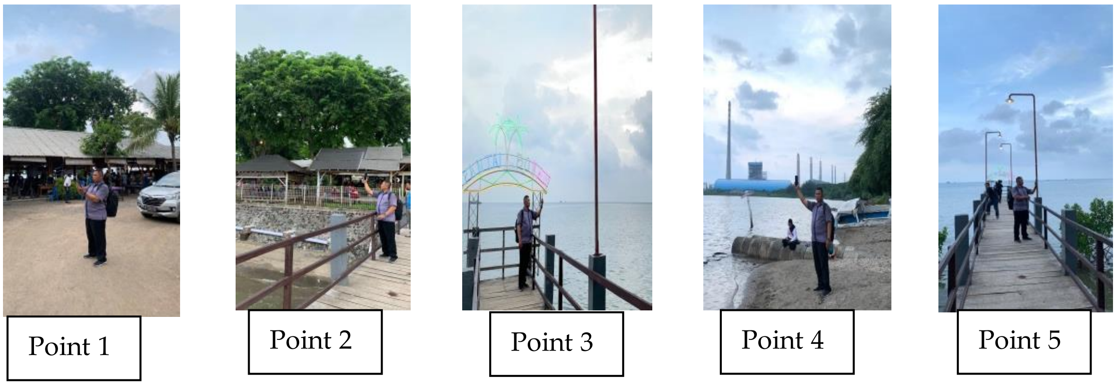

Figure 5. Wind speed graph at 16.01 WIB.

Experimental results indicate that as the day progresses towards noon, wind power output tends to increase due to the rising intensity and velocity of wind, which typically reaches its peak during midday. However, the generated power is not consistently stable, as it is influenced by several external factors such as overcast or rainy weather conditions, the presence of trees obstructing sunlight, and physical obstacles that alter wind direction. Similarly, as the afternoon approaches and solar radiation diminishes, wind speed and intensity gradually decrease, leading to a reduction in generated power output. Based on field measurements conducted at Bohay Beach, Paiton, it was observed that wind speed exhibits a significant increase as the day progresses towards noon, mirroring the patterns described in Table 1. Nonetheless, the wind velocity at this location is subject to fluctuations due to environmental factors affecting air flow dynamics, such as coastal topography, vegetation barriers, and atmospheric conditions prevalent in the Probolinggo coastal region.

The wind power output derived from the measured wind speed data using the Zephyrus WindMeter application is summarized in Table 3. Assuming a rotor swept area of 3 m², the analysis reveals that the lowest wind power recorded is 0 Watts at an average wind speed of 0 m/s, while the highest power output reaches 28.7 Watts at an average wind speed of 2.5 m/s. Wind turbines are recognized as a viable technology for harnessing wind energy, where a generator converts kinetic wind energy into electrical energy. Wind turbines are broadly classified into two categories: Horizontal Axis Wind Turbines (HAWTs) and Vertical Axis Wind Turbines (VAWTs). HAWTs are capable of achieving high efficiency and generating substantial power output; however, they require relatively high wind speeds to initiate rotation. On the other hand, VAWTs, particularly the Savonius-type vertical axis turbine, can capture wind from all directions and possess self-starting capabilities, allowing them to rotate even at low wind speeds while producing high torque. Nonetheless, VAWTs generally exhibit lower efficiency compared to their horizontal counterparts.

Table 2. Wind Power Calculation Results

Wind Speed (m/s)	Wind Power (Watt)
0	0
0.1	0.0018
0.3	0.05
0.5	0.23
0.6	0.3
0.7	0.63
0.8	0.9
0.9	1.34
1	1.84
1.3	4
1.4	5
1.5	6.2
1.6	7.5
1.7	9
2.2	19.6
2.3	22.36
2.5	28.7

Simulation results with a four-blade turbine configuration set at mounting angles of 35° and 40°, under wind speeds of 5 m/s and rotational speeds of 500 RPM, yield a power output between 246.83 Watts to 255.62 Watts, making it suitable for small-scale residential electricity generation in rural areas. The measurement data obtained from Bohay Beach, Paiton, however, indicates that the location has a relatively low wind energy potential for conventional wind power generation applications. The recorded power output is significantly lower compared to values reported in existing studies capable of supporting household-scale electricity production.

Alternative solution to mitigate low wind speed limitations involves utilizing specialized low-wind-speed turbines available in the market, such as the Honeywell WindTronics Wind Turbine. This type of turbine has been effectively deployed in coastal and marine energy hybrid systems, complementing solar photovoltaic systems at the Paiton Coastal Renewable Energy Center (PLTH). Given the relatively low wind resource potential at Bohay Beach, integrating low-speed wind turbines like WindTronics offers a practical alternative to enhance the feasibility of wind energy applications in this region.

3.2 Discussion

The findings from wind speed measurements at Pantai Bohay Paiton indicate that the site possesses a relatively low average wind speed, ranging between 0 m/s to 2.5 m/s, with peak wind speeds occurring during midday periods. This trend is consistent with previous studies indicating that coastal wind intensities generally peak during the late morning to early afternoon due to thermal differences between land and sea, which drive sea breeze circulation patterns. However, the relatively low magnitude of wind speed measured throughout the observation period suggests that the area may not be suitable for conventional horizontal-axis wind turbines (HAWT) that require higher cut-in wind speeds to operate efficiently [13-14].

These who observed that wind energy potential in several Indonesian coastal regions is often limited by fluctuating wind conditions influenced by topographical obstructions, weather variations, and diurnal thermal shift. Consequently, alternative turbine technologies such as Vertical Axis Wind Turbines (VAWT) – specifically Savonius-type designs – are more appropriate for low-wind-speed areas due to their capability to initiate rotation (self-starting) at lower wind thresholds and their omnidirectional wind capture capability [15].

Furthermore, technological solutions such as Honeywell WindTronics Wind Turbine systems, designed for low wind speeds starting from 0.5 m/s, offer a viable option for micro-generation applications in such low-wind areas. These turbines could serve as complementary systems to existing solar photovoltaic (PV) installations, providing a hybrid renewable energy system for small-scale off-grid coastal communities.

The study also underlines the importance of accurate site assessment using field measurements rather than relying solely on regional wind atlases, as local environmental factors such as vegetation density, terrain, and anthropogenic obstructions significantly influence microclimatic wind profiles. The discrepancy between theoretical wind potential and practical energy output highlights the need for tailored renewable energy system design, including turbine selection optimized for the specific wind resource characteristics of a given site

Nevertheless, the low wind power density measured at Pantai Bohay Paiton (maximum recorded wind power of 28.7 Watts at 2.5 m/s) limits its feasibility as a standalone power generation solution for large-scale applications. Thus, a hybrid renewable energy strategy incorporating solar PV and wind micro-turbines is recommended to address electricity needs in remote coastal zones. Further research should consider extended data collection over longer periods, including seasonal variations, as well as computational simulations of turbine performance under varied wind regimes to validate the practical deployment of low-wind-speed turbine technologies.

4. Conclusion

This study has evaluated the wind energy potential at Bohay Beach, Paiton, Probolinggo, using direct field measurements with the Zephyrus WindMeter application. The findings indicate that the site exhibits relatively low wind speeds, with a maximum average wind speed of 2.5 m/s, resulting in a peak power output of only 28.7 Watts when assuming a 3 m^2 rotor swept area. Such values are insufficient for conventional wind turbine systems designed for higher wind speeds and large-scale energy production. However, given the site's continuous albeit modest airflow, alternative solutions such as low-wind-speed turbines (e.g., Honeywell WindTronics) are recommended as a complementary energy source, particularly in hybrid systems alongside solar photovoltaic installations. The deployment of customized turbine technology for low-wind-speed environments could help mitigate the current energy limitations faced in coastal areas like Bohay Beach, thereby supporting local energy needs, enhancing rural electrification initiatives, and promoting the utilization of renewable energy resources. Future research is recommended to incorporate long-term wind pattern assessments and explore hybrid system designs to optimize energy generation in regions with similar wind characteristics.

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