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Analysis of Wind Energy Potential and Technical Evaluation of a Small-Scale Wind Turbine for Electricity Generation in Batam, Indonesia

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ABSTRACT

Wind energy represents one of Indonesia's most promising renewable energy resources, with a national potential estimated at approximately 60 GW. However, its implementation remains limited due to insufficient site-specific assessments and feasibility studies. This research analyzes the wind energy potential at Galang District Beach, Batam City, and evaluates the technical suitability of the Sky Dancer 500 (TSD 500) wind turbine equipped with inversed-taper blades for small-scale electricity generation. A descriptive quantitative method was employed using secondary wind speed data from NASA (2014–2018) and primary measurements collected continuously for 30 days. Results show that Galang District Beach, Batam City exhibits average wind speeds ranging from 4 to 13.41 m/s, with a maximum recorded speed of 13.41 m/s. Based on technical analysis, low-speed wind characteristics align well with the operational profile of a horizontal-axis wind turbine utilizing inversed-taper blades. Estimations indicate that the TSD 500 turbine can generate 390–500 Wh of electricity per day under the observed wind conditions. These findings demonstrate that the site possesses adequate potential for micro-scale wind power development, and deploying ten units of the TSD 500 turbine could supply daily electrical needs for approximately ten households. The study contributes to the growing body of literature on decentralized renewable energy solutions for remote and coastal communities in Indonesia..

KEY WORDS: *Wind Energy Potential, Coastal Wind Assessment, Renewable Energy, Small-Scale Wind Turbine, Galang District Beach.*

NOMENCLATURE

P	wind power (W)
ρ	air density (kg/m³),
A	rotor swept area (m²)
V	wind speed (m/s)
Cp	power coefficient
φ	electrical efficiency

1.0 INTRODUCTION

The demand for electrical energy in Indonesia has grown rapidly over the past two decades, driven by population growth, urbanization, industrial development, and the increasing penetration of digital technologies across both urban and rural sectors. This persistent rise in electricity consumption places a substantial burden on the national energy supply system, which continues to rely predominantly on fossil fuels such as coal, diesel, and natural gas. As a consequence, Indonesia faces a dual challenge: ensuring energy security while simultaneously reducing dependence on finite and environmentally detrimental fossil energy resources. This situation is further compounded by fluctuations in global fossil fuel prices and the environmental commitments that Indonesia has pledged under various international climate agreements. In this context, renewable energy development becomes not only a strategic necessity but also an opportunity to promote sustainable, decentralized, and resilient energy systems.

Among the various renewable energy resources available in Indonesia, wind energy stands out as an underutilized yet highly promising option. Presidential Regulation No. 22/2017 concerning the National Energy Plan (RUEN) estimates that Indonesia has a theoretical wind energy potential of approximately 60 GW, distributed across 34 provinces. Despite this impressive potential, the contribution of wind energy to the national energy mix remains negligible compared to solar, hydropower, and geothermal resources. One of the key factors limiting wind energy adoption is the lack of detailed, site-specific assessments that characterize the actual wind profile at local scales. Such assessments are essential because Indonesia's geographical and meteorological conditions are highly diverse; while some regions experience strong and consistent wind flows, others exhibit low or irregular patterns that may not support galang district Beach, Batam City, represents one such location where empirical wind data remain limited. The area is characterized by hilly coastal terrain, which theoretically supports the formation of favorable wind patterns due to the interaction between land-sea breezes and topographic elevation. Local communities in the region currently rely on electricity supplied by the state-owned utility (PLN), but the geographical challenges and the distance from major power distribution hubs make energy supply vulnerable to disruptions and relatively costly expansion. Therefore, identifying alternative and complementary sources of energy—particularly small-scale, decentralized renewable systems—is highly relevant to improving energy resilience and community welfare.

The present study addresses this gap by conducting a comprehensive assessment of wind speed characteristics and analyzing the technical feasibility of using the Sky Dancer 500 (TSD 500) wind turbine—specifically designed for low wind speed conditions—to harness energy at the site. The study integrates long-term secondary wind data from NASA with primary field measurements collected continuously over 30 days. By examining both meteorological patterns and turbine performance parameters, this research aims to provide an accurate estimation of the electrical energy that can be generated and offer scientific evidence to support potential micro-scale wind power development in Galang Beach district. This contributes to broader efforts to accelerate renewable energy adoption in Indonesia, particularly in rural and coastal communities that stand to benefit significantly from decentralized energy systems..

2.0 METHOD

The methodology of this study was designed to systematically evaluate the wind energy potential at Galang District Beach, Batam City, an area characterized by coastal wind dynamics and open-sea exposure. A descriptive quantitative research approach was adopted to obtain both long-term wind characteristics and short-term on-site measurements. This approach was selected to ensure that the resulting data accurately represent the temporal variability of coastal wind patterns, which are crucial for determining the feasibility of small-scale wind turbine deployment.

The study utilized two complementary data sources: secondary wind speed data from the National Aeronautics and Space Administration (NASA) and primary field measurements collected directly at Galang District Beach. The secondary data were obtained from NASA's Surface Meteorology and Solar Energy (SSE) database, covering a five-year period from 2014 to 2018, with measurements referenced at a standard height of 10 meters above ground level. These long-term datasets provide a broad understanding of regional wind regimes, seasonal fluctuations, and interannual variability typical of coastal environments. Such data are essential for identifying trends and confirming whether the selected site consistently exhibits wind speeds within the operational thresholds of small-scale wind turbines.

To complement and validate the secondary dataset, primary wind speed measurements were conducted on-site for a duration of 30 consecutive days, with data recorded continuously over 24-hour cycles. Measurements were taken using an anemometer installed at a height equivalent to the hub height of the proposed turbine to ensure realistic energy estimation. Temperature, atmospheric pressure, and humidity were also recorded, as these parameters influence air density, which in turn directly affects wind power calculations. The geographic elevation of the measurement site was documented to adjust atmospheric variables using standard fluid mechanics equations.

Air density (ρ) at the site was calculated using the ideal gas law adjusted for local atmospheric conditions, incorporating measured temperature and pressure. Given that Galang District is located near sea level, the density correction primarily accounted for temperature fluctuations typical of tropical maritime climates. Atmospheric pressure was estimated using standard barometric formulas, ensuring accuracy in subsequent wind power calculations.

Wind power potential was calculated using the classical kinetic energy equation:

$$P=1/2\rho Av^3$$

where P is the wind power (W), ρ is air density (kg/m³), A is the rotor swept area (m²), and v is the wind speed (m/s). To estimate electrical power output, turbine-specific performance coefficients were incorporated. The Sky Dancer 500 (TSD 500) wind turbine, known for its suitability in low-to-moderate wind speed environments, was selected as the reference model. Parameters considered include the turbine's power coefficient (Cp), electrical efficiency (φ), cut-in and rated wind speeds, and rotor area. The electrical power was calculated using the modified formula:

$$P_{elec}=1/2\rho Av^3C_p\phi$$

This approach integrates real turbine performance with site-specific wind characteristics, ensuring more accurate projections. To assess daily and hourly energy potential, wind speed data were processed into statistical distributions, including frequency histograms, diurnal patterns, and mean daily wind profiles. These analyses enabled identification of periods with highest energy production potential, particularly during hours influenced by coastal sea breezes. The integration of long-term and short-term datasets allowed the study to capture both macro-level trends and micro-level wind behaviors unique to Galang District Beach, providing a comprehensive foundation for evaluating the feasibility of deploying small-scale wind turbines in this coastal region..

3.0 RESULT

The analysis of wind characteristics and the estimated energy output at Galang District Beach, Batam City was conducted using both secondary and primary datasets. The results derived from NASA wind speed records (2014–2018) and 30 days of on-site measurements show a consistent coastal wind pattern influenced by maritime climatic conditions. The findings presented in this section highlight wind speed variability, daily distribution patterns, wind power potential, and projected electrical output using the TSD 500 wind turbine.

The secondary data indicate that average annual wind speeds at Galang District Beach ranged between 4 m/s and 13.41 m/s, with the highest mean values typically occurring during the June–August monsoon period. During this interval, monthly wind speeds often exceeded 5 m/s, demonstrating a seasonal intensification driven by the southwest monsoon. In contrast, the December–February period recorded the lowest mean speeds, generally between 3.0 m/s and 3.5 m/s. The long-term dataset also shows that wind speeds surpassed 7 m/s on several isolated days each year, confirming the presence of periodic high-energy wind events typical of coastal regions. The frequency distribution reveals that wind speeds in the 3–4 m/s range

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occurred most frequently, accounting for approximately 160–180 days per year.

The primary field measurements, collected continuously for 24 hours across 30 consecutive days, provide a more detailed and localized view of the diurnal wind cycle. The recorded wind speeds ranged from 1.2 m/s to 10.84 m/s, with an average daily wind speed between 2.8 m/s and 4.6 m/s depending on the measurement day. Maximum speeds above 8 m/s were typically observed between 13:00 and 17:00, coinciding with peak sea-breeze activity. During early morning hours (00:00–06:00), wind speeds were significantly lower, often remaining below 2 m/s, and rarely exceeding the turbine cut-in threshold. Across the 30-day period, wind speeds above 3 m/s were available for approximately 8–11 hours per day, indicating a stable daily operational window for energy harvesting.

Air temperature measurements during the field campaign ranged from 26.1°C to 31.8°C, contributing to air density values between 1.15 kg/m³ and 1.19 kg/m³, consistent with typical tropical maritime conditions. These air density values were incorporated into the wind power calculations. Using the kinetic wind power formula, the average wind power available per hour ranged from 55.42 W to 184.63 W, depending on the wind speed on the measurement day. The highest instantaneous wind power recorded was 1,290.41 W, corresponding to a wind speed of 10.84 m/s.

The estimated electrical output of the Sky Dancer 500 (TSD 500) wind turbine was calculated using the manufacturer's performance parameters, including rotor swept area, power coefficient, and electrical efficiency. The projected daily electrical energy generation during the 30-day measurement period ranged from 385.16 Wh to 527.44 Wh, depending on the average wind speed for each day. The highest estimated daily output (527.44 Wh) occurred on a day when the mean wind speed reached 4.6 m/s, while the lowest value corresponded to mean speeds slightly above the turbine's cut-in range. On average, the turbine is capable of producing approximately 430–500 Wh per day under typical wind conditions at Galang District Beach.

Overall, the results demonstrate that Galang District Beach exhibits a consistent diurnal wind pattern, adequate average wind speeds for small-scale wind turbine operation, and a predictable daily window for electricity generation..

4.0 DISCUSSION

The results obtained from the long-term NASA dataset and the 30-day on-site measurements reveal that the wind characteristics at Galang District Beach, Batam City are consistent with those typically observed in coastal tropical environments, where wind regimes are strongly influenced by sea–land breeze circulations. The daily pattern, marked by low wind speeds during the early morning and increased velocities in the afternoon, aligns with established coastal meteorological principles, suggesting that the site benefits from stable diurnal wind cycles. This pattern is particularly relevant for small-scale wind energy systems, as predictable wind windows enhance operational reliability and energy planning for local communities.

When compared to studies conducted in other Indonesian coastal regions—such as Ciheras Beach, South Sulawesi's coastal plains, and several locations in the Riau coastal corridor—the wind speed range at Galang District Beach (4.8–6 m/s on average) falls within the lower-to-moderate category. Previous literature indicates that many Indonesian coastal zones exhibit similar wind behaviors, where typical speeds range from 3 to 6 m/s. This reinforces the conclusion that Galang District is representative of Indonesia's broader coastal wind profile, making it suitable for micro-scale wind turbine applications rather than large-scale wind farms. The predominance of wind speeds in the 3–4 m/s range further supports the selection of a small turbine model designed for low wind speed operation.

The use of the Sky Dancer 500 (TSD 500) in this analysis is justified by its aerodynamic and structural characteristics, particularly its inversed-taper blade geometry and cogging-less generator technology. Numerous aerodynamic studies have demonstrated that inversed-taper blades yield superior performance under low wind speed conditions due to their enhanced lift-to-drag ratios and efficient rotational initiation. This aligns with the findings in the present study, where the TSD 500 turbine showed a consistent ability to generate between 385 and 527 Wh per day despite the relatively modest wind speeds. The estimated output falls within the performance envelope reported in prior research on similar small-scale turbines operating in low-speed coastal environments.

Furthermore, the daily operational window of 8 to 11 hours above the turbine's cut-in speed is notable. This window corresponds to the period when sea-breeze circulation intensifies due to temperature differentials between land and ocean surfaces. The predictability of this pattern enhances the turbine's reliability as an energy source and provides a stable foundation for potential integration with hybrid systems, such as solar photovoltaic installations, which also peak during daylight hours. The complementary nature of wind and solar resources in coastal tropical climates presents an opportunity for combined systems that can deliver more consistent energy output.

The estimated daily electrical energy output of approximately 430–500 Wh indicates that a single TSD 500 turbine can supply basic electricity needs for lighting, device charging, and small appliances. If scaled to a cluster of ten turbines, the system could meaningfully supplement or partially replace grid electricity for several households. This has particular significance for Galang District, where certain areas remain distant from centralized grid infrastructure and where decentralized renewable systems can enhance energy resilience.

In summary, the wind characteristics observed at Galang District Beach, combined with the turbine's low-wind performance, confirm that the site is suitable for micro-scale wind energy generation. The findings align well with existing research in similar tropical coastal contexts and demonstrate that decentralized wind energy solutions hold promise for supporting local energy needs in the region.

4.0 CONCLUSION

The assessment of wind characteristics and estimated turbine performance at Galang District Beach, Batam City demonstrates that the area possesses meaningful potential for small-scale wind energy generation. The integration of long-term NASA wind datasets and 30 days of continuous on-site measurements provides a comprehensive representation of the local wind regime. The findings confirm that wind speeds at the site consistently fall within the low-to-moderate category, with average daily values ranging between 4 and 13.41 m/s and maximum speeds reaching 13.84 m/s during peak afternoon hours. These wind conditions are strongly influenced by predictable sea–land breeze cycles, offering a stable and repeatable daily operational window of approximately 8 to 11 hours above the turbine cut-in threshold.

Based on these measured wind characteristics, the Sky Dancer 500 (TSD 500) wind turbine—optimized for low wind speed environments—was identified as an appropriate technological match for the site. Calculations incorporating air density, rotor swept area, and turbine performance coefficients indicate that the TSD 500 is capable of producing approximately 385 to 527 Wh of electrical energy per day under typical coastal wind conditions in Galang District. This level of output is sufficient to meet basic electrical needs for a household when deployed individually, and substantially more when implemented as a multi-turbine microgeneration system.

Overall, the results confirm that Galang District Beach is a viable location for micro-scale wind energy development, particularly for decentralized applications aimed at supporting residential or community-level energy needs. The combination of consistent daily wind patterns, adequate mean speeds, and compatibility with low-speed turbine technology makes the site a promising candidate for renewable energy integration. The study thus provides foundational evidence supporting the deployment of small-scale wind systems in coastal regions of Batam, contributing to broader efforts to expand sustainable and resilient energy infrastructure in Indonesia..

REFERENCE

[1] Alimuddin, S., & Daud, P. (2005). Studi Potensi Energi Angin Di Kota Palu Untuk Membangkitkan Energi Listrik. Jurnal SMARTek, 3(1), 21–26. Retrieved from http://jurnal.untad.ac.id/jurnal/index.php/SMARTEK/article/view/336.

[2] Bachtiar, A., & Hayattul, W. (2018). Analisis Potensi Pembangkit Listrik Tenaga Angin. Teknik Elektro, 7(1), 35–45.

[3] Handoko, A. D. W. I. (2019). Jenis Semi-Inversed Taper Untuk Angin Berkecepatan Angin Rendah. Fakultas Teknik Universitas Surya: Tangerang.

[4] Hau, E. (2015). Wind turbines. In Fluid Mechanics and its Applications (Vol. 109). https://doi.org/10.1007/978-94-017-9627-9_10

[5] Nawawi, I., & Fatkhurrozi, B. (2016). Sistem Pembangkit Listrik Tenaga Angin Skala Kecil Pada Bangunan Bertingkat. Jurnal Teknik Elektro, 1(1), 1–7. https://doi.org/10.1001/jamadermatol.2014.3002

[6] Otieno Saoke, Churchill, Joseph Ngugu Kamau, Robert Kinyua, Yohifumi Nishizawa, I. U. (2015). Power Performance of an Inversely Tapered Wind Rotor and its Air Flow Visualization Analysis Using Particle Image Velocimetry (PIV). American Journal of Physics and Applications, 3(1), 6. https://doi.org/10.11648/j.ajpa.20150301.12

[7] Perpres No. 22/2017. (n.d.). Tentang Rencana Umum Energi Nasional (RUEN).

[8] Piggott, H. (1997). Windpower Workshop. USA: centre for alternative technology.