Evaluating Wind Energy Potential in the Negros Island Region: Regional Analysis and Feasibility Assessment

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Abstract

This study evaluated the wind energy potential of selected coastal and inland locations in the Negros Island Region using quantitative analysis of wind speed data. The research aimed to assess wind characteristics by computing the mean wind speed, wind speed range, and wind speed frequency percentage for each selected site. Wind speed values from locations including Tanjay City, Dumaguete City, San Carlos City, Bayawan City, Bacolod City, and Escalante City were analyzed to compare wind behavior across different geographic settings. Results revealed that coastal locations, particularly Bacolod City and Dumaguete City, exhibited higher and more stable mean wind speeds compared to inland and partially sheltered areas. Wind speed variability across all sites was generally low to moderate, indicating relatively consistent wind conditions, while frequency analysis showed recurring wind speeds that suggest predictability is important for energy planning. Although the observed wind speeds may not be sufficient for large-scale wind farm development, the findings indicate that small-scale or community-based wind energy systems are feasible in certain coastal areas. The study highlights the influence of geographic factors such as coastal exposure, terrain, and proximity to open seas on wind behavior and provides baseline information to support future renewable energy planning and research in the Negros Island Region.

Keywords: Wind energy potential, wind speed analysis, coastal wind characteristics, small-scale wind energy, Negros Island Region

Introduction

The rising worldwide electricity demand and a greater focus on climate change and environmental sustainability have propelled the worldwide shift towards the use of renewable sources of energy. Among these sources of energy, wind energy has become a relatively mature form of renewable energy as it has been widely used around the world for electricity generation as it does not produce any greenhouse gas emissions when generating electricity ("World Energy Outlook 2023," 2023). Across the world, the development of wind energy is largely affected by the wind speed of a location as it is a basic physical parameter influencing the efficiency of electricity generation by wind energy ("World Energy Outlook 2023," 2023). Both onshore and offshore wind energy projects are suitable in regions with moderate to high wind speeds, as per several research studies conducted across the world (Global Wind Energy Council [GWEC], 2023; A Roadmap for Offshore Wind in the Philippines, 2022). The Philippine government has made it a priority to develop renewable energy to improve energy security and reduce reliance on imported fossil fuels. Wind energy development is an integral part of this transformation in the country, as per the Renewable Energy Act of 2008 and other policies (Department of Energy [DOE], 2022). Geographic location, height, and proximity to large monsoon winds such as the Northeast Monsoon (Amihan) and the Southwest Monsoon (Habagat) affect the availability of wind resources in the country, as supported by assessments of wind resources conducted in the country (PAGASA, 2022). Based on data collected and analyzed by national and international bodies, regions near bodies of water and elevated areas receive higher wind speeds and hence can be suitable for converting wind energy (DOE, 2022; National Renewable Energy Laboratory [NREL], 2023). Existing wind energy farms can be found in Northern Luzon; other locations suitable for similar conditions remain uninvestigated and undeveloped in terms of research.

The Negros Island Region presents interesting but yet to be explored local opportunities in the development of wind energy. The presence of varied terrain, extensive coastlines, and the movement of monsoons seasonally create diverse winds in the region, which might help in the generation of wind energy. Though the inner and high-lying regions might benefit from the acceleration of winds due to terrain, the coastal regions experience the effect of the sea-land breeze phenomenon (World Bank, 2023). Wind speed is directly associated with the potential of wind energy and is considered the dependent variable because it represents the capacity of the winds to generate electrical power. It is considered the independent variable in this research. However, despite the rising electricity requirements brought about by population increase, urbanization, as well as economic activities like agriculture, tourism, and industry, extensive and site-specific wind resource assessments in the Negros Island Region remain limited (DOE, 2022; PAGASA, 2024). The majority of wind resource studies in the Philippines had been conducted in areas where wind farms had already been established, creating a knowledge gap in regions like Negros Island which have suitable terrain and climate conditions but had not been extensively studied yet.

This research aims to assess the wind energy potential of the Negros Island Region by investigating and evaluating wind data such as wind speed, wind direction, and seasonal variation based on accessible secondary data, wind maps, and relevant literature regarding wind potential. Generally, this research aims to respond to essential research questions such as what areas in Negros Island have the highest potential for wind energy development, to what extent wind resources in Negros can be used for small, community-based, or commercial wind energy projects, and what aspects or variables affect wind energy development in Negros. By integrating global principles of wind energy assessment, national renewable energy objectives, and local geographic characteristics, the study aims to provide a systematic and evidence-based evaluation of wind energy potential in Negros Island. The research is limited to an initial analysis of wind energy potential, not using direct wind data but using data from other sources such as government publications, literature, and existing research on wind energy. Thus, it might have missed micro-level wind patterns created by vegetation, terrain, or urban planning. Moreover, though environmental and social issues have been raised in general, this research has not used technical, economic, or financial feasibilities such as cost-benefit analysis, connectivity to the electricity supply, or risk analysis for investments. The research is exclusively on wind energy; it does not compare wind energy to other sources of renewable energy such as solar or hydro energy. Thus, results of this research should not be used for an initial research to promote further research, not to implement an idea immediately.

The applicability of this study's findings on the development of sustainable and renewable energy resources in the Philippines is evident. This study can also be used as a reference for planning and formulation on where best to locate the development of wind energy in the future, which is important for government institutions and decision-makers. This study can provide crucial information on development planning that can aid in the advancement of clean energy projects, the decrease in reliance on fossil fuels, and the enhancement of local energy security through the creation of community-based renewable energy resources. This report can also be used as a reference by investors and developers in the reduction of investment risk and uncertainties for wind energy projects within their targeted location. This report can also be used as a reference by investors and developers in the reduction of investment risk and uncertainties for wind energy projects within their targeted location. This report can also be used as a reference on how best to promote the benefits of wind energy towards a cleaner and healthier environment through the reduction of greenhouse gas emissions, cleaner air, and increased energy security. Lastly, this research can help academics and students learn more about wind energy, hybrid renewable energy sources, and sustainable energy development planning.

Literature Review

Wind energy is a form of renewable energy that generates electricity by using wind turbines to harness the kinetic energy of the air or wind. Due to its sustainability, low greenhouse gas emissions, and minimal environmental impact in comparison to other sources like fossil fuels, wind energy is also widely sought after ("Renewable Power Generation Costs in 2023," 2024).

Recent studies have also highlighted the importance of wind energy in the fight against climate change because it reduces emissions and enhances future energy security by improving a nation's energy mix (Global Wind Report 2022, n.d.; Climate Change 2022: Mitigation of Climate Change, n.d.). The Philippines has a significant potential for wind energy due to its location along the Pacific Ring of Fire, its long coastline, and its exposure to monsoon winds.

Wind energy has been identified by the Department of Energy of the Philippines as one of the major fields for renewable energy development under the Renewable Energy Act of 2008 through feed-in tariffs, renewable portfolio standards, and other economic incentives (DOE, 2022). Existing wind energy projects in Northern Luzon already prove that wind energy can be both feasible and economical if sufficient wind resources and infrastructure are provided (DOE, 2023).

However, most wind resource assessment studies undertaken on a national level have conventionally concentrated on areas that already have known good wind resources. Consequently, areas with moderate wind resources could possibly be neglected. Current research has emphasized the need for localized wind resource assessment studies, especially for island communities (World Bank, 2020). These studies give a more realistic representation of wind resources in a location, taking into consideration wind speed, direction, terrain, and micro-climates that might not be reflected on a national wind resource assessment (PAGASA, 2021).

Research indicates that for small-scale or community-based wind energy development, an average wind speed of 4 to 6 meters per second is adequate, especially when combined with solar energy resources (IRENA, 2021; Asian Development Bank [ADB], 2019). Notably, these studies emphasize the necessity of wind resource assessment studies at the municipal and coastal city levels, which are excellent for decentralized wind energy applications but may not have enough wind resources for large-scale wind energy development. Furthermore, a local evaluation that connects national renewable energy policy with local resource availability is crucial, according to research on renewable energy policy (World Bank, 2020; "World Energy Outlook 2023," 2023). In this sense, it is crucial to do a local study on wind energy that supports sustainable development objectives, helps communities create sustainable energy, and reduces dependency on imported fossil fuels.

Methodology

In this study, a quantitative-descriptive research design was used to assess the potential for wind energy in the chosen locations in the Negros Island Region. A quantitative design is fitting since the study is using numerical data on the wind, such as wind speed values, which were analyzed using elementary statistical analyses. The design also allowed for a systematic description and interpretation of major wind factors such as average wind speed values. The study made use of secondary quantitative data collected from trusted sources such as PAGASA's wind speed values and directions, renewable energy reports by the DOE, and other published studies on the assessment of the potential for wind energy. The data is accurate and sufficient for the assessment. The choice of the design is also appropriate since it is a study that aims to describe the potential for wind energy.

The area of study included a few areas along the coasts of the Negros Island Region, which were selected due to the availability of high monsoon winds, elevation, and proximity to the coastline. The topography of the Negros Island supported the study of geographical variations of wind energy potential because there were possibilities of comparisons in terms of wind variables according to the area. The past wind speed and direction information was collected using the Windy web tool that provides past wind speed or wind direction information on a real-time platform according to wind models and wind stations. The wind speed measured in meters/second (m/s) was collected for study purposes using wind speed information that is appropriate for use according to the area and time. Sample wind speed information was shown using tables that demonstrate the use of statistics in research work for wind speed measurement in different seasons according to the major wind seasons.

Wind speed is the independent variable in this research. This refers to the rate at which air moves horizontally past a given location. The measurement is done in meters per second (m/s). The importance of wind speed in relation to wind energy is that it is a major factor determining the potential kinetic energy that can be tapped for the generation of electricity. The efficiency or effectiveness of using wind energy is directly linked to the intensity of the airflow. This is because the higher the intensity of the airflow, the higher the efficiency. In comparison to other sites, the higher intensity is observed in coastal and elevation areas where the flow is faster and more consistent ("World Energy Outlook 2023," 2023; Philippine Atmospheric, Geophysical & Astronomical Services Administration [PAGASA], 2021). The potential for wind energy is the dependent variable. This is the capacity of a place to generate useful electrical power from the wind that is present. The wind's qualities determine the potential. The distribution of wind speeds, the average wind speed, and the stability or consistency are all included in this. A location's potential for exploiting its wind to generate electricity increases with the constancy of its wind speeds. This is closely related to the airflow intensity levels (Department of Energy [DOE], 2023; Intergovernmental Panel on Climate Change [IPCC], 2022).

Certain control factors are taken into into consideration during the study in order to guarantee the validity of the analysis. These include altitude, exposure to prevailing wind patterns, and location, where the geographical characteristics of being an coastal area play a significant role in determining wind patterns and ensuring that wind speed is the primary contributor to the variance in wind energy (World Bank, 2020; PAGASA, 2021).

Also, the duration during which data is collected is managed to reduce the impact of seasonal variability, especially in areas where monsoon systems, such as in the Philippines, may result in varying wind directions and speed during different periods of the year (PAGASA, 2021). Secondly, feasibility criteria are used in a standardized manner to determine if wind speed is adequate enough to be considered for wind energy purposes. This is done to ensure that wind energy potential is not overestimated in areas where wind speed is not optimal ("World Energy Outlook 2023," 2023).

Conceptual Framework

The collected wind speed data were analyzed using descriptive statistical techniques. The following formulas were applied to evaluate wind energy potential:

Formula 1: Mean Wind Speed
To determine the average wind condition existing at a particular location over a particular time duration, the mean wind speed was calculated. The mean wind speed is one of the measures used to determine overall wind condition and is defined as "the average wind velocity at a particular location over a specified period of time" (PAGASA, 2021).

$$\bar{V} = \frac{\sum V}{n}$$

Where:
$\bar{V}$ = Mean wind speed (meters per second, m/s)
$\sum V$= Sum of all recorded wind speed values
n= Total number of wind speed observations

Formula 2: Wind Speed Range
The wind speed range indicates the variation between the highest and lowest wind speed values. Wind speed range measures the variability of wind conditions by determining the difference between the maximum and minimum recorded wind speeds. This metric helps assess wind stability, which is critical for evaluating wind energy feasibility (Li et al., 2025).

$$Range = V_{max} - V_{min}$$

Where:
V_{max} = Maximum recorded wind speed (m/s)
V_{min} = Minimum recorded wind speed (m/s)

Formula 3: Wind Speed Frequency Percentage
This formula determines the percentage of wind speed observations that fall within the usable range for wind energy generation. Wind speed frequency percentage represents the proportion of wind speed observations that fall within a usable range for wind energy generation. Frequency analysis is widely applied in wind energy studies to determine the consistency and reliability of wind resources at a given site ("Wind Speed Frequency Distribution Modeling and

Wind Energy Resource Assessment Based on Polynomial Regression Model. International Journal of Electrical Power & Energy Systems.," n.d.)

$$\boldsymbol{Frequency}\ (\%) = \left(\frac{\boldsymbol{f}}{\boldsymbol{n}}\right) \times \mathbf{100}$$

Where:
f = Number of wind speed observations within the usable wind speed range
n = Total number of wind speed observations

Results

The result of the assessment of the potential of wind energy in the Negros Island Region is presented in this study. The assessment was conducted in specific sites in the Negros Island Region. The result was generated from the analysis of the data on the mean wind speed, the range of the wind speed, and the frequency percentage of the wind speed, which are the major indicators of the behaviors of the winds or the potential of the winds to provide energy.

This result is essential in the assessment of the potential of the winds in different coastal sites, specifically in the sites where the mean wind speed is relatively high and stable to provide an adequate amount of energy. This analysis is essential in providing data on the predictability of the behaviors of the winds, which is essential in planning and executing small-scale wind energy projects to benefit the communities. This study provides an empirical approach to the assessment of the potential of the Negros Island Region to develop wind energy in the coastal sites.

Table 1. Wind Speed and Wind Direction Measurements with Derived Statistical Indicators for Evaluating Wind Energy Potential

Location	Wind Speed	Mean Wind Speed	Wind Speed Range	Frequency Percentage
Tanjay City (Negros Oriental)	3m/s NE 2m/s N 1m/s N	2m/s	2	33.33% for 1m/s,2m/s and 3m/s
Dumaguete City (Negros Oriental)	5m/s NE 4m/s NE 3m/s N	4m/s	2	33,33% for 5m/s,4m/s,3m/s
San Carlos City (Negros Occidental)	3m/s NE 2m/s NE 3m/s N	2.67m/s	1	33.33% for 2m/s and 66.67% for 3m/s

Bayawan City (Negros Oriental)	3m/s E 1m/s NE 3m/s NE	2.33m/s	2	33.33% for 1m/s and 66.67% for 3m/s
Bacolod City (Negros Occidental)	5 m/s N 4m/s NE 4m/s N	4.33m/s	1	33.33% for 5m/s and 66.67 for 4m/s
Escalante City(Negros Occidental	3m/s NE 2m/s E 2m/s NE	2.33m/s	1	33.33% for 3m/s and 66.67% for 2m/s

However, unlike other sites such as Tanjay City, Bayawan City, San Carlos City, and Escalante City, it was found that coastal sites, especially in Bacolod City and Dumaguete City, have generally faster and steadier mean wind speeds. The results of the frequency analyses indicated the repeat occurrence of wind speeds that provide some degree of predictability, an important consideration for energy development, while the range of wind speeds for different sites was generally of low to moderate values, an indication that wind conditions were fairly stable. To summarize, it appears that small-scale or community-based wind energy development might be worthwhile for some coastal sites while wind energy can provide an alternative energy source, albeit wind speeds are not yet adequate for pursuing large wind farm developments for renewable energy in the Negros Island Area.

Solution

Using the formulas:

$$\bar{V} = \frac{v_1 + v_2 + v_3}{n}$$

$$Range = V_{max} - V_{min}$$

$$Frequency\ (\%) = \frac{f}{n} \times 100$$

The researchers have substituted the variables with the given values.

Table 2: Summary of Wind Speed Statistics Across Selected Cities in Negros Island

Location	Given	Mean Wind Speed	Wind Speed Range	Frequency Percentage
Tanjay City (Negros Oriental)	v1=3 m /s v2=2 m/s v3=1 m/s	3+2+1/3=3/6=2.00 m/s	3−1=2 m/s	1/3×100=33.33%
Dumaguete City (Negros Oriental)	v1=5 m/s v2=4 m/s v3=3 m/s	5+4+3/3=12/3=4.00 m/s	5−3=2 m/s	1/3×100=33.33%
San Carlos City (Negros Occidental)	v1=3m/s v2=2m/s v3=3m/s	3+2+3/3=8/3=2.67m/s	3-2=1m/s	2/3×100=66.67% 1/3×100=33.33%
Bayawan City (Negros Oriental)	v1=3 m/s v2=1 m/s v3=3 m/s	3+1+3/3=7/3=2.33m/s	3-1=2m/s	3m/s×100=66.67% 1m/s×100=33.33%
Bacolod City (Negros Occidental)	v1=5 m/s v2=4 m/s v3=4 m/s	5+4+4/3=13/3=4.33m/s	5-4=1m/s	4m/s×100=66.67% 5m/s×100=33.33%
Escalante City (Negros Occidental)	v1=3 m/s v2=2 m/s v3=2 m/s	3+2+2/3=7/3=2.33m/s	3-2=1m/s	2m/s×100=66.67% 3m/s×100=33.33%

Discussion

The results of the study indicate that wind energy potential in several coastal areas of the Negros Island Region differs considerably due to variations in wind speed strength, consistency, and frequency. Among the locations examined, Bacolod City and Dumaguete City show higher average wind speeds 4.33 m/s and 4.00 m/s, respectively making them more suitable for wind energy development compared to other coastal areas with lower values. Previous research emphasizes that mean wind speed is the most critical factor in assessing wind energy potential because power output increases exponentially with wind speed. Even small increases can lead to substantial gains in energy production (IEA, 2023). In addition, the relatively stable wind speed patterns observed in these cities further enhance their suitability, as consistent winds improve turbine efficiency, operational reliability, and long-term energy planning (Renewable Energy Statistics 2023, 2023; Global Wind Report 2022, n.d.).

Tanjay City, Bayawan City, San Carlos City, and Escalante City have lower average wind speeds than other places, which may indicate a reduced potential for wind energy. These findings do not, however, completely exclude out wind energy use in these regions. Research indicates that wind power can still be beneficial in areas with mean wind speeds between 2.0 and 3.0 m/s, especially when paired with solar energy systems to assist mitigate wind intermittency (World Bank, 2020; WWEA, 2021). Additionally, these areas are appropriate for community-based wind energy projects that value stability and dependability over high power output because moderate wind speeds are frequently linked to lower wind variability (World Energy Outlook 2023, 2023).

The potential for wind energy production in a number of coastal places is further supported by the examination of wind speed frequency. In Bacolod City, San Carlos City, Bayawan City, and Escalante City, the high recurrence of certain wind speeds (66.67%) indicates rather predictable wind patterns, which are generally regarded as necessary for efficient wind energy planning and system design (NREL, 2023). Such predictability improves the economic sustainability of wind projects, particularly at the community level, and helps lower uncertainty in energy output predictions. On the other hand, the more uniformly distributed wind speed frequencies seen in Tanjay City and Dumaguete City suggest more varied but usually stable wind conditions, which would still be appropriate for small-scale turbines built to function well in lower wind regimes (IEA, 2023).

Geographical and atmospheric variables are primarily responsible for the differences seen among the coastal regions. Because of sea-land breeze circulation and reduced surface roughness, which let airflow to travel more easily than in protected or highly populated areas, coastal locations typically receive stronger and more constant winds (World Bank, 2023; PAGASA, 2021). Furthermore, the Philippines' dominant monsoon patterns are believed to improve seasonal wind consistency along coastlines, making them even more suitable for the development of wind energy (DOE, 2022; PAGASA, 2024). These results are consistent with studies conducted both domestically and internationally that show coastal areas to be among the best locations for wind energy harvesting because of their better wind conditions (GWEC, 2023; World Energy Outlook 2023, 2023).

The differences in wind characteristics found while assessing the wind energy potential of the chosen coastal locations in the Negros Island Region are in line with results from previous wind energy studies. Since the power output of wind turbines is related to the cube of wind speed, mean wind speed continues to be the most important consideration when evaluating wind energy potential. Therefore, potential energy generation can grow significantly with even a little increase in average wind speed (International Energy Agency [IEA], 2023). Given their comparatively higher average wind speeds, this relationship explains why Bacolod City and Dumaguete City show more promise for wind energy development than the other locations. Aside from the mean wind speed, the remaining locations' generally low to moderate wind speed ranges indicate more constant wind behavior, which makes them ideal for distributed and small-scale wind energy system.

Previous studies show that reduced wind speed variability is associated with more stable and predictable energy production, thereby improving system reliability and planning accuracy (Z. Wang & Liu, 2021; Yu et al., 2024). Furthermore, the wind speed frequency distributions identified in this study—characterized by repeated occurrences of specific wind speeds—suggest predictable wind regimes, which are essential for reliable energy yield estimation and appropriate turbine selection. Although large-scale wind farms typically require higher average wind speeds, existing research demonstrates that small-scale and community-based wind systems can still operate effectively in moderate wind conditions, especially when integrated with complementary renewable sources such as solar energy (*Multi-criteria Assessment of Potential Regions for Wind Power Generation in the State of Rio De Janeiro*, n.d.) The influence of geographic factors, including coastal exposure, terrain, and proximity to open seas, further supports these findings, as coastal environments are known to enhance wind flow through sea–land breeze circulation and reduced surface roughness.

The results show that the coastal locations in the Negros Island Region show acceptable wind conditions for small-scale wind energy projects, even though they may not yet be appropriate for large-scale wind farms. These programs have the potential to significantly contribute to the region's energy source diversification and sustainable development (Renewable Energy Statistics 2023, 2023; World Bank, 2020). The study also emphasizes how crucial it is to carry out site-specific wind studies in order to determine the best renewable energy options for any place.

Conclusion

By having useful guidance for creating sustainable energy solutions that are appropriate for the local environment, this study is anticipated to benefit the Negros Island Region. By doing this, the area may become more energy resilient and less dependent on imported fossil fuels. According to the research, coastal regions are ideal for small-scale or community-based wind energy projects because they have higher average wind speeds, consistent wind patterns, and frequent wind occurrences. In addition to supporting national and international sustainability goals, these projects might assist coastal towns fulfill their energy needs, offer more dependable electricity, lower long-term costs, and reduce greenhouse gas emissions (Renewable Energy Statistics, 2023; Global Wind Report, 2022).
As a means to address the variability of wind resources, this study's main recommendations are that local government units perform trial projects for small-scale wind systems, integrate localized wind evaluations into energy planning, and support hybrid energy programs that combine solar and wind power. By employing domestic renewable resources, increasing energy generation predictability, and guaranteeing technical viability, these actions would assist solve the problems associated with a constrained and fossil fuel-dependent energy supply (World Bank, 2020; DOE, 2022). Additionally, studies have shown that wind metrics like average wind speed, wind speed range, and wind speed frequency are crucial markers for assessing the performance and suitability of turbines in small-scale energy projects (PAGASA, 2021; Global Wind Report, 2022).

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