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Small-Scale Wind Turbine Installation in Barangay Bagasbas Daet, Camarines Norte, Philippines: A Wind Resource Assessment

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Abstract

The wind characteristics in Barangay Bagasbas Daet, Camarines Norte, by way of 5-year wind data at a 10-m elevation was analyzed using the data received from the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA). The overall mean wind speed in the area is 3.36 m/s at 75 degrees North of East. By way of the Weibull model, an annual wind density of 52.7 W/m^2 was recorded to fit the wind data distribution. With power curves of 3 kW(V), 5 kW(V), 10 kW(V), 10 kW(H), and 20 kW(H), a small-scale turbine was used to estimate the annual energy generation. The expected annual energy production for a 20 KW(H) wind turbine is about 17,095.23 kWh/year. However, the 5 kW(V) wind turbine showed the highest capacity factor of 13.97%.

Keywords: wind energy, Bagasbas Daet wind assessment

1. Introduction

Recently, small-scale wind energy is starting to gain popularity because of its application in urban and remote areas that are unreachable by an electricity grid. Its prospect for utilization is dependent on an accurate and comprehensive wind energy resource evaluation. Using the information, a suitable site can be made and an appropriate wind energy conversion technology can be selected. The wind resource evaluation of the small-scale wind industry is different from the large-scale wind industry, as the latter is already established. The total investment cost on a turbine was prohibitively high and, thus, was impractical for the time scales of the small-scale wind industry [1]. Additionally, a power of 10 KW was sufficient for household use.

If turbines are sized properly, they can provide a reliable source of energy for developing countries [2]. Studies have been conducted to evaluate wind energy potential for small-scale wind turbines. The wind speed characterization in the Incek region of Ankara, Turkey was studied using wind data at 20 m and 30 m heights. Data were taken as 1 min average values for one year from June 2012 to June 2013. The results showed a maximum power density of about 98 (W/m2) encountered in March. Small-scale wind turbines' performance was investigated and they were found capable of providing yearly energy needed for an average household in Turkey [3]. Chandel

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et al. [4] determined the wind energy potential of the western Himalayan region at 1 min, 10 min, hourly and daily intervals. Furthermore, vertical wind profiles at different height hubs were also determined. The results showed that at wind speeds ranging from 1 to 16 m/s throughout the year, the location is best suited for small-scale wind energy systems up to 5 kWp with a low cut in windspeeds of 1.5–2.5 m/s.

The statistical characteristic of the wind speed in the province of Alicante, Spain was determined using 9-year wind data recorded at 2m [5]. The result showed an overall wind speed of 1.7 m/s, which was maximum in spring-summer during the central hours of the day and minimum in autumn-winter at night. Wind frequency distribution showed a multimodal pattern and a high number of calm hours. This was modeled using the sum of log normal, giving a good fit with an r2 > 0.99. The potential use of small-scale turbines in the area is limited, hence hybrid systems were recommended. Farhan et al. [6] explored the wind production prospective of one of the sites in the south region of Pakistan. At four different altitudes with individual wind power densities, frequency distribution can be generated through calculation in commercial wind turbines. Weibull parameters were calculated using 5 numerical methods. Results showed a yearly mean wind speed of 6.172 m/s and a power density of 310 W/m2 at 80m height with high power density from April to August. The cost per kWh of electricity is estimated to be 0.0263 US$/kWh. The study site was recommended for the installation of small standalone systems as well as wind farms.

In the Philippines, by 2030, a target is set to increase the renewable energy capacity by 200%, with a 2500 MW wind power contribution. Countrywide evaluation for the potential of wind energy was done but few or no studies have been conducted to assess the country's wind energy potential for small-scale wind system application. The Philippines' wind range, based on the Wind Energy Resource Atlas Report, was from 6.4 to 10 m/s, yielding an estimate of 300-1,250 W/sq.m [7]. It is noted that the Philippines' wind resource was strongly dependent on elevation, proximity, and latitude to the coastline, with the best wind resources situated in the north and northeast and the worst ones in the south and southwest. Tagum et al. [8] conducted continuous wind measurement and monitoring to establish the wind patterns and determine the wind resource potential of the Philippines in the north-eastern part of Luzon and one of its islands. Results showed an annual average wind speed of 4.97m/s in Sta. Ana, Cagayan, and 5.9 m/s and 5.2 m/s wind speed were calculated from east and southwest, respectively.

The objective of this paper is to study the wind characterization of Barangay Bagasbas Daet, Camarines Norte, focusing on the wind potential for small-scale wind turbine applications.

2. Analysis of Meteorological Data

2.1. Overview of Barangay Bagasbas Daet, Camarines Norte and Data Source

The Philippines, as shown in Fig.1a, is an archipelago consisting of 7,641 islands and situated in the middle of the West Philippine Sea (formerly known as the South China Sea) and the Pacific Ocean. The climate is tropical and maritime, which is characterized by relatively high temperature, humidity, and abundant rainfall. The average annual temperature for the country is 26.6 °C, with January being the coolest month, recording a mean temperature of 25.5 °C and May being the warmest month with a mean temperature of 28.3 °C. The average monthly relative humidity varies between 71% in March and 85% in September. The mean annual rainfall varies from 965 to 4,064 millimeters. The climate of the country is divided into two major seasons: (1) the rainy or wet season, from May to October; and (2) the dry season, from November to April.

On the other hand, Daet is a first-class municipality and the capital of the province of Camarines Norte from the Bicol Region as seen in Fig.1b. It has a coordinate of 14 08′ 18″ (latitude) and 122

Figure 1: *(a) Map of the Philippines showing the Camarines Norte region, (b) Map of Camarines Norte showing the municipality of Daet, and (c) A photograph of the PAGASA weather station in Daet.*

58′ 46" (longitude). Daet has a total land area of 72,483 hectares with 0–8% slope and is generally considered flat due to its location near the coastal area. Fig.1c shows the 25 Barangays of Daet with a population of 104,799 people as of 2015. Barangay Bagasbas in Daet was considered as a surfing spot by the Department of Tourism owing to its windy environment; hence it is the interest area for the study. The main electricity source of the region is geothermal energy. However, the supply is unreliable and frequent blackouts occur in the area. Thus, the study for another possible source of electricity is needed.

The wind data is taken 10 meters from the ground by the synoptic weather station of the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) located at Barangay Bagasbas, Daet, Camarines Norte. The wind data recorded every 3 hours for 5 years from 2012 to 2016 was collected and statistically analyzed. Fig. 2a shows a photograph of the PAGASA Daet Station and Fig. 2b shows the meteorological mast present. Table 1 shows the nominal specifications of the equipment used such as the anemometer and the wind vane.

Figure 2: *The meteorological mast present in Barangay Bagsbas, Daet, Camarines Norte PAGASA Weather Station*

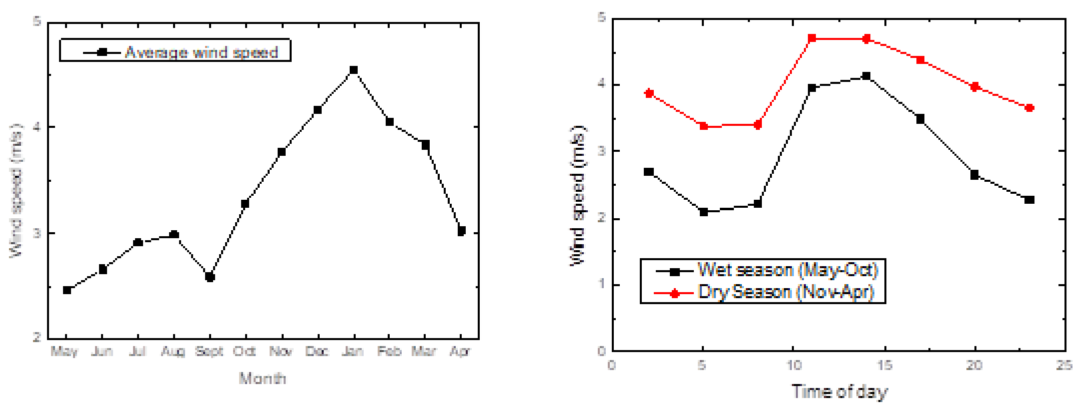
Table 1: *Nominal specifications of the equipment used in the study*

Equipment	Measuring range	Accuracy	Installation height
Anemometer	0 – 70 mps	± 0.5 mps below 10 m/s ± 5% above 10 mps	10 m
Wind Vane	360° continuous	± 5°	10 m

2.2. Wind Speed Pattern and Wind Direction

The monthly average wind speed at 10-m above the ground from the five-year data is shown in Fig.3a. The highest monthly average wind speed occurred in January at 4.55 m/s, while the lowest occurred in May at 2.47 m/s. The annual average wind speed was 3.35 m/s. The wind speed is relatively higher in the dry season from November to April than in the wet season from May to October. Fig.3b shows the diurnal evolution of wind speed throughout the day, separated by wet and dry seasons. The highest average wind speed occurred at 11 am with 4.71 m/s for the dry season while the lowest average wind speed occurred at 5 am with 2.10 m/s during the wet season.

Another important thing that needs to be considered is the wind direction. Fig. 4 shows the wind rose diagrams of the monthly average wind direction of Daet at 10m from the ground. WRPlot View Software was used for wind rose plotting. During mid-November to mid-February, the cool and dry northeast monsoon winds, also called Amihan, are dominant in the Philippines. From mid-June to mid-September, the warm and wet southeast monsoon, or Habagat, bring humid air, thick clouds, and heavy rains. In the figure above, the wind is more stable from November to April which also gives the relatively higher wind speed values. The average wind direction during the wet season is 24° SW and 66° NE in the dry season.



(a) *Monthly average wind speed of Daet for 2012-2016*

(b) *Diurnal evolution of wind speed throughout the day*

Figure 3: *Wind speed patterns*

2.3. Determination of Weibull Parameters

The on-site wind speed data measurements were recorded at 1-min,10-min, and hourly intervals by way of a probability distribution for wind speed characterization. The two statistical analyses

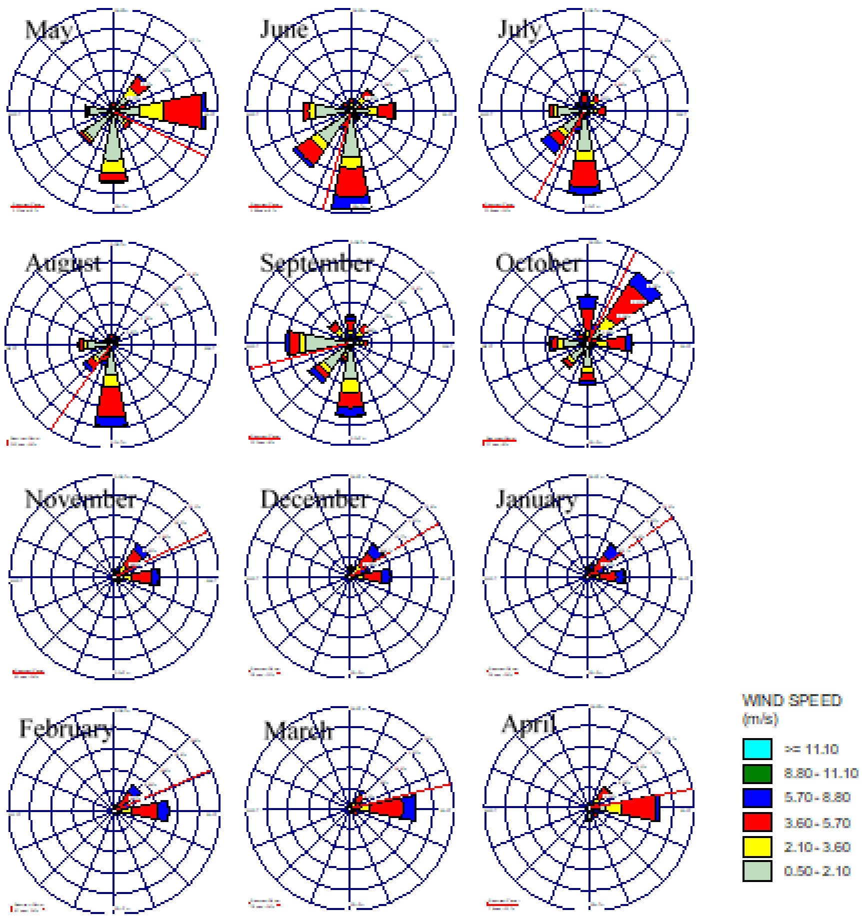


Figure 4: *Monthly wind rose diagrams for wind direction*

were done using Weibull and log-norm distribution [9], and it gives a good fit.

Furthermore, Islam et al. [10] discussed that by including the calculation of a wind resource, a Weibull distribution function can be used because of its simplicity. Cabello et al. [11], on the other hand, do not recommend using Weibull distribution for high frequency or modality.

Two parameter functions can be used for the probability of wind speed. A probability density function can be used where an area for wind speed is under investigation, while the cumulative distribution function assesses the potential of a turbine in an area [10]. The wind speed probability density function and cumulative distribution function are calculated using the Equation 1 and 2, respectively [3,6,10,12].

$$f(v) = (\frac{k}{c})(\frac{v}{c})^{k-1}exp[-(\frac{v}{c})^k], (k > 0, v > 0, c > 0) \tag{1}$$

$$F(v) = 1 - e^{-(\frac{v}{c})^k} \tag{2}$$

where v is the wind speed value and k and c are the shape and scale parameters, respectively.

Chang et al. [13] reviewed the six kinds of numerical techniques namely moment method, empirical method, graphical method, maximum likelihood method (MLM), modified maximum likelihood method, and energy pattern factor method for the Weibull estimation of parameters.

Results showed that modified MLM, MLM, and moment method has good performance, while the graphical and empirical method was susceptible for a large dataset.

Farhan et al. [6] observed that the MLM method, modified MLM method, empirical method, and energy pattern factor method gave better and fitting results for the wind data measured at the southern region of Pakistan. Islam et al. [10] used the empirical method for estimating the 2-parameter Weibull distribution for the assessment of wind energy potential at Kudat and Labuan, Malaysia, from 2006 to 2008. In this study, the researchers used to estimate the Weibull parameters is the empirical method.

The empirical method requires the mean wind speed ($\bar{v}$) and standard deviation of the wind speed data (σ), defined as Equation 3 and 4, respectively [14];

$$\bar{v} = \frac{1}{n}\sum_{i=1}^{n} v_i \tag{3}$$

$$\sigma = [\frac{1}{n-1}\sum_{i=1}^{n}(v_i - \bar{v})^2] \tag{4}$$

The shape (k) and scale (c) parameter can be found using the following equation [15]:

$$k = (\frac{\sigma}{\bar{v}})^{-}1.086, (1 \leq k \leq 0) \tag{5}$$

$$c = \frac{\bar{v}}{\Gamma(1 + \frac{1}{k})} \tag{6}$$

$\Gamma(x)$ is the gamma function and is expressed as [16]:

$$\Gamma(x) = \int_0^{\infty} t^{x-1} e^{-1} dt \tag{7}$$

RMSE was also calculated using the following equation:

$$RMSE = [\frac{1}{N}\sum_{i=1}^{N}(f^*(v_i) - f(v_i)^2]^{\frac{1}{2}} \tag{8}$$

where N is the number of observations, $f^*(v_i)$ is the observed frequency and $f(v_i)$ is the frequency calculated from the Weibull distribution function.

The average wind speed, calculated shape (k), and scale (c) parameters are shown in Table 2. The low value of RMSE shows that the empirical method used for the determination of the Weibull parameters is satisfactory for the region under this study. Fig. 5 shows the monthly probability density function of the observed wind speed and the Weibull distribution.

2.4. Vertical Extrapolation of Wind Speed

Wind speed increases proportionately as the vertical height increases, hence there is a need to adjust the recorded wind speed according to the interest vertical height. Justus and Mikhail [17] discussed the importance of having thorough project height variations in the wind speed probability distribution. Wind data is extrapolated to the hub height by using 1/7th wind power law or by a power factor known as wind shear factor (α) or coefficient. Rehman and Al-Abbadi [18] noted that wind shear coefficients directly affect the energy production and plant capacity factor. Inaccurate calculation of the wind shear factor may either lead to underestimation or overestimation of wind speed, hence the underestimation or overestimation of wind energy. Various solutions for vertical

Table 2: *Monthly average wind speed and Weibull parameters at 10 m height*

	10m			
Month	Ave. wind speed (m/s)	k	c (m/s)	RMSE
May	2.47	1.783	2.775	0.004
June	2.66	1.560	2.959	0.004
July	2.94	1.535	3.252	0.004
August	2.97	1.588	3.314	0.004
September	2.59	1.473	2.864	0.004
October	3.29	1.761	3.692	0.003
November	3.74	2.197	4.227	0.002
December	4.18	1.669	4.682	0.003
January	4.55	2.019	5.133	0.003
February	4.05	2.303	4.572	0.003
March	3.77	2.323	4.259	0.003
April	3.03	2.082	3.422	0.004

wind profiles are currently being used, either based on experience or mathematical models such as the power law, logarithmic law, and numerical models. In this study, the power law was utilized and is described in Equation 9 [19],

$$\frac{v_1}{v_2} = (\frac{h_1}{h_2})^{\alpha} \tag{9}$$

where v_1 (m/s) is the measured value of wind speed at reference heights h_1 (m), v_2 (m/s) is the measured value of wind speed at height h_2 (m), and α designates the power-law exponent or wind shear exponent from the following equation:

$$\alpha = (0.37 - 0.0881 \ln V_2)(1 - 0.0881 \ln(h_2/10)) \tag{10}$$

Table 3 shows the monthly average wind speeds for the observed data at 10m and the extrapolated wind speed values at 20m and 30m. There is an increase of up to 30% wind speed from 10m to 30m. The seasonal average wind speed for 10 m, 20 m, and 30 m is shown in Table 4. The corresponding Weibull parameters and their RMSE values for monthly and seasonal wind speeds were shown in Tables 5 and 6, respectively.

3. Wind Energy Assessment in Daet

3.1. Wind Power Density

Wind power density is the energy across a unit area per unit time and is considered as a representation of the wind energy potential of a certain region [20]. Wind power density is described by Equation 11:

$$P(v) = \frac{1}{2} p v^3 A \tag{11}$$

where p is the standard air density at sea level with a mean temperature of 15 °C and pressure of 1 atm (1.225 kg/m3) and v is the mean wind speed (m/s).

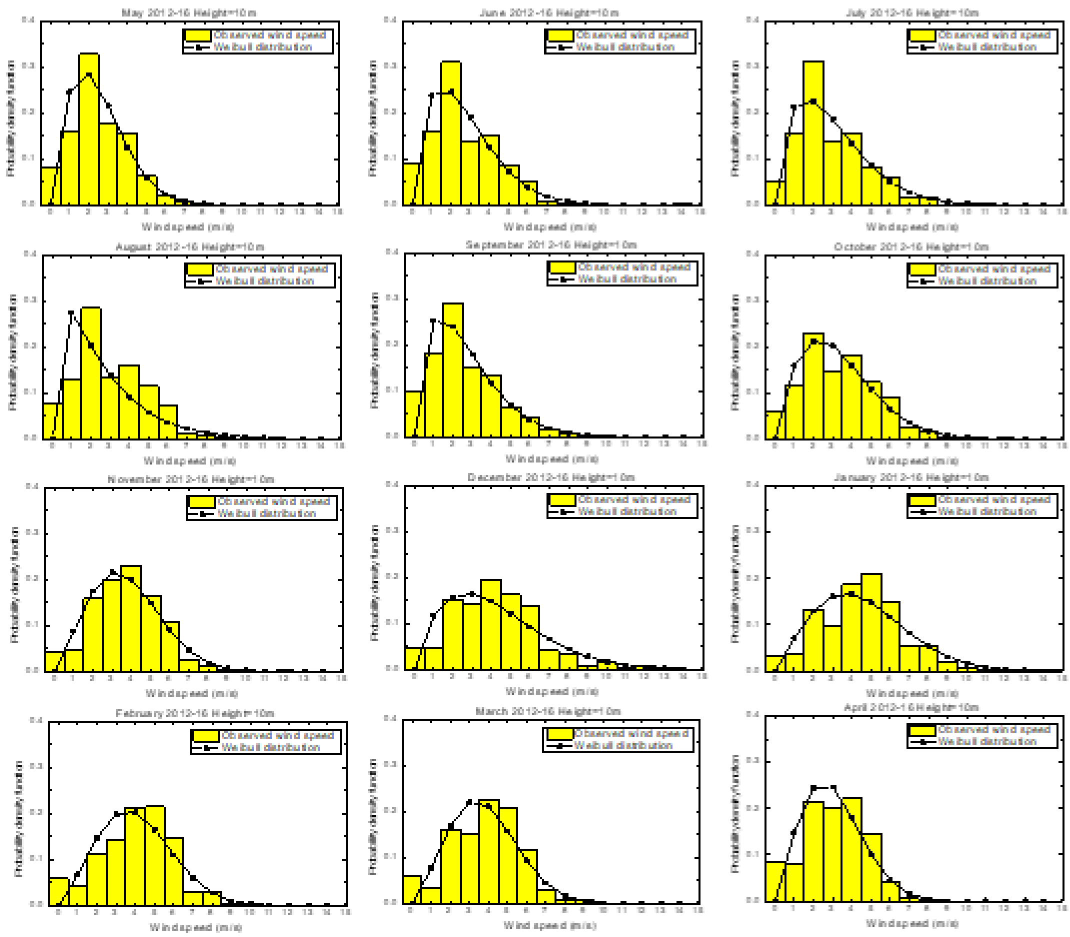


Figure 5: *Monthly probability density function*

The most probable wind speed (v_{mp}) and wind speed carrying maximum energy ($v_{max,E}$) are the significant wind speeds for wind energy estimates [4]. Their respective values through Weibull parameters are given in Equation 12 and 13 [20]:

$$v_{mp} = c(1 - \frac{1}{k})^{\frac{1}{k}} \tag{12}$$

$$v_{max,E} = c(1 - \frac{2}{k})^{\frac{1}{k}} \tag{13}$$

The wind speed and the maximum energy values for each month and season were done in Tables 7 and 8, respectively. According to the calculated values, the maximum wind speed occurred in January and in the dry season, while the minimum wind speed occurred in September and in the wet season.

Wind power density can also be determined using the Weibull probability distribution as described in Equation 14 [21].

$$\bar{P} = \int_0^\infty \frac{1}{2} p v^3 f(v) dv = \frac{1}{2} p c^3 \Gamma(1 + \frac{3}{k}) \tag{14}$$

Table 3: *Monthly average wind speeds for the observed data at 10m and extrapolated data at 20m and 30m height*

Month	Average wind speed (m/s) 10 m	20 m	30 m
May	2.47	2.95	3.24
June	2.66	3.17	3.47
July	2.90	3.43	3.75
August	3.00	3.55	3.88
September	2.60	3.08	3.38
October	3.24	3.81	4.16
November	3.76	4.41	4.80
December	4.15	4.83	5.23
January	4.53	5.25	5.68
February	4.08	4.76	5.16
March	3.80	4.44	4.83
April	3.05	3.61	3.95

Table 4: *Seasonal average wind speed for 10m, 20m and 30m*

Season	Average wind speed (m/s) 10 m	20 m	30 m
Wet	2.81	3.33	3.65
Dry	3.90	4.155	4.94

Table 5: *Weibull parameters for monthly wind speed values*

	10 m			20 m			30 m		
Month	k	c	RMSE	k	c	RMSE	k	c	RMSE
May	1.783	2.775	0.004	1.873	3.323	0.007	1.925	3.659	0.007
June	1.560	2.959	0.004	1.650	3.533	0.007	1.701	3.883	0.008
July	1.535	3.252	0.004	1.638	3.872	0.006	1.697	4.249	0.007
August	1.588	3.314	0.004	1.689	3.935	0.006	1.745	4.312	0.007
September	1.473	2.864	0.004	1.554	3.424	0.007	1.601	3.766	0.007
October	1.761	3.692	0.003	1.856	4.353	0.005	1.910	4.753	0.006
November	2.197	4.227	0.002	2.325	4.950	0.004	2.398	5.385	0.006
December	1.669	4.682	0.003	1.807	5.466	0.005	1.885	5.933	0.006
January	2.019	5.133	0.003	2.148	5.948	0.004	2.221	6.433	0.006
February	2.303	4.572	0.003	2.413	5.325	0.005	2.475	5.776	0.007
March	2.323	4.259	0.003	2.431	4.981	0.004	2.492	5.415	0.007
April	2.082	3.422	0.004	2.170	4.048	0.006	2.220	4.427	0.007

Additionally, the wind energy density (E) can be found by multiplying the wind power density by the desired time (T) in hours as shown in Equation 15.

$$E = \frac{1}{2} pc^3 \Gamma(1 + \frac{3}{k}) T \quad (15)$$

Table 6: *Weibull parameters for seasonal wind speed values*

	10 m			20 m			30 m		
Season	k	c	RMSE	k	c	RMSE	k	c	RMSE
Wet	1.5791	3.1416	0.0015	1.6729	3.7403	0.0026	1.7264	4.1045	0.0070
Dry	1.9386	4.3870	0.0013	2.0658	5.1271	0.0018	2.1373	5.5708	0.0064

Table 7: *Most probable wind speed and maximum energy carrying wind speed values for 12 months*

	10 m		20 m		30 m	
Month	$v_{mp}(m/s)$	$v_{max,E}(m/s)$	$v_{mp}(m/s)$	$v_{max,E}(m/s)$	$v_{mp}(m/s)$	$v_{max,E}(m/s)$
May	1.749	4.231	2.211	4.897	2.501	5.297
June	1.535	5.021	2.009	5.716	2.307	6.132
July	1.636	5.601	2.177	6.304	2.516	6.723
August	1.772	5.538	2.313	6.251	2.648	6.678
September	1.325	5.126	1.763	5.830	2.041	6.249
October	2.292	5.681	2.868	6.456	3.224	6.915
November	3.206	5.675	3.886	6.464	4.300	6.934
December	2.707	7.507	3.499	8.256	3.972	8.708
January	3.659	7.219	4.442	8.080	4.914	8.588
February	3.570	5.997	4.265	6.839	4.686	7.338
March	3.342	5.564	4.005	6.376	4.408	6.858
April	2.499	4.728	3.045	5.469	3.381	5.913

Table 8: *Most probable wind speed and maximum energy carrying wind speed values for two seasons*

	10 m		20 m		30 m	
Season	$v_{mp}(m/s)$	$v_{max,E}(m/s)$	$v_{mp}(m/s)$	$v_{max,E}(m/s)$	$v_{mp}(m/s)$	$v_{max,E}(m/s)$
Wet	1.664	5.275	2.170	5.985	2.486	6.409
Dry	3.018	6.324	3.722	7.116	4.147	7.588

The calculated wind power density and wind energy values at 10 m, 20 m, and 30 m heights are presented in Tables 9 and 10. The power density with the highest values was found in the dry season and in January for all the heights. The wind energy generation potential of the sites is classified according to the average power density values given in Table 11. The maximum wind power density value for Daet is 109.1 W/m^2 in January at 10 m and 196.2 W/m^2 at 30m. However, the annual average wind power density is 52.7 W/m^2. Thus, the region can be considered as power class 1, which indicates low wind energy potential. This can be further utilized using small-scale wind turbines.

3.2. Small Wind Turbine Production and Cost Analysis

Due to the low wind energy potential in Bagasbas Daet, small-scale wind turbines were investigated. Five variations of the AEOLOS three-bladed horizontal axis wind turbines were selected for this purpose. The characteristics of these five wind turbines are given in Table 12. These turbines were selected due to their relatively low cut-in speed and rated speed values so that more energy

Table 9: *Wind power density and wind energy density values for 12 months*

Month	10 m $P(W/m^2)$	10 m $E(kWh/m^2)$	20 m $P(W/m^2)$	20 m $E(kWh/m^2)$	30 m $P(W/m^2)$	30 m $E(kWh/m^2)$
May	19.931	14.829	32.166	23.932	41.585	30.939
June	29.594	21.308	45.984	33.108	58.317	41.988
July	40.431	30.080	61.254	45.573	76.686	57.054
August	40.358	30.026	61.361	45.653	76.989	57.280
September	29.760	21.427	46.146	33.225	58.436	42.074
October	47.764	35.536	73.142	54.418	91.964	68.421
November	56.195	40.460	86.162	62.037	108.397	78.046
December	105.187	78.259	149.750	111.414	181.743	135.217
January	109.066	81.145	159.742	118.848	196.207	145.978
February	68.378	45.950	104.379	70.143	130.937	87.990
March	54.911	40.854	84.967	63.215	107.350	79.868
April	31.321	22.551	49.884	35.917	64.003	46.082

Table 10: *Wind power density and wind energy density values for two seasons*

Season	10 m $P(W/m^2)$	10 m $E(kWh/m^2)$	20 m $P(W/m^2)$	20 m $E(kWh/m^2)$	30 m $P(W/m^2)$	30 m $E(kWh/m^2)$
Wet	34.699	153.232	53.430	235.946	67.437	297.801
Dry	71.118	308.939	106.170	461.202	131.848	572.749

Table 11: *Wind power classification [22]*

Power class	Power density at 10 m (W/m^2)	Power density at 30 m (W/m^2)
1 (poor)	≤ 100	≤ 160
2 (marginal)	≤ 150	≤ 240
3 (moderate)	≤ 200	≤ 320
4 (good)	≤ 250	≤ 400
5 (excellent)	≤ 300	≤ 480
6 (excellent)	≤ 400	≤ 640
7 (excellent)	≤ 1000	≤ 1600

generation can be achieved. The power curves for the five turbines were shown in Fig. 6.

The hub heights of the turbines were selected according to the manufacturer's specifications. Since the hub heights are different from the initial extrapolated values, which were 20m and 30m, another extrapolation was done for 12m and 18m heights.

The annual occurrence time and the annual energy production can be calculated using Equation 16 and 17 respectively as shown below:

$$Occurrence\,time(h) = f(V) \times 8760h \tag{16}$$

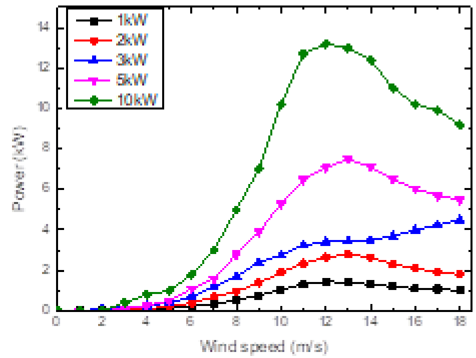


Figure 6: *Power curves for the selected wind turbines*

Table 12: *Characteristics of the selected small-scale wind turbines*

	AEOLOS-V 3kW	AEOLOS-V 5kW	AEOLOS-V 10kW	AEOLOS-H 10kW	AEOLOS-H 20kW
Rated capacity (W)	3000	5000	10000	10000	20000
Rotor diameter (m)	3.2	4	5	6.4	8
Hub height (m)	9	12	12	18	18
Cut in speed (m/s)	3	2.5	2.5	3	3
Rated speed (m/s)	14	12	12	10	10
Cut out speed (m/s)	18	13	14	10	10
Swept area (m^2)	8.04	12.57	19.63	32.17	50.27

$$Pw = \sum (P(V) \times f(V) \times 8760) \tag{17}$$

where Pw is the annual energy production (kWh), $P(V)$ is the electric power output (kW) of the wind speed V, and $f(V)$ is the occurrence rate of the wind speed V.

Meanwhile, the capacity factor (C_f) of the wind turbine is the ratio of its actual output over some time. When the annual capacity factor of a turbine is 17% or over, it is considered to be desirable.

Wind energy costs can be assessed through such methods. This might cause the adaptability of this system in certain locations for installation. These factors can be categorized if the system is viable through the manner of its maintenance, operation, and investment cost [23].

To determine the energy cost of kWh produced by the turbine, the present value of cost (PVC) was calculated. PVC has been done under the following assumptions [23–25]:

- The method of the present value of the money is used to determine the costs.
- The machine is assumed to have a lifetime of 20 years.

- The interest rate (r) and the inflation rate (i) are said to be 3 and 3.2%. This was based on the Philippines inflation rate [26].
- The operation, repair, and maintenance costs (C_{OMR}) are estimated by 25% of the annual cost of the machine (machine price/lifetime). This is based on the Philippine Installation and Commissioning of Wind Measurement Equipment [8].
- The salvage value S is taken to be 10% of the investment of machines and civil work. This data is taken from the Philippine Installation and Commissioning of Wind Measurement Equipment [8].
- An investment of an amount of I includes the turbine price plus its 20% for the civil work, the connection cables to the grid, and other setup costs.

Under the above assumptions, the present value of the costs PVC is:

$$PVC = I + C_{OMR}(\frac{1+i}{r-i})(1 - \frac{1+i}{1+r})^n - S(\frac{1+i}{1+r})^n \quad (18)$$

where I is the investment cost, C_{OMR} is the operation, maintenance, and repair cost, i is the inflation rate, r is the interest rate, n is the lifetime of the machine (in years) and S is the salvage value.

The unit cost of energy (CPU) can be obtained by dividing the Present Value Cost (PVC) by the total energy generated by the wind turbine during its entire lifetime [26].

Using cost analysis, the minimum cost of energy obtained was 0.52 c$/kWh for GWE-V 3kW and the maximum cost of energy was 1.73 c$/kWh for AEOLOS-H 20kW. However, taking the account of capacity factor, the AEOLOS-V 5 kW is better at 13.97% with a CPU of 0.58 c$/kWh.

4. Conclusion

In this paper, the 5-year wind speed data recorded in a 3-hour interval at Bagasbas Daet, Camarines Norte, was statistically analyzed using the Weibull probability distribution function. The significant outcomes of the study are summarized below.

(1) The highest monthly average wind speed occurs in January at 4.55 m/s, while the lowest is in May at 2.47 m/s. The annual average wind speed is 3.35 m/s.

(2) A higher wind speed average was noted at 4.71 m/s in the dry season from November to April while the lowest average at 2.10 m/s during the wet season which is from May to October was recorded. Moreover, results using WRPlot View software for wind rose plotting showed that the months from November to April presents a more stable wind direction compared to the other months which are affected by Amihan or Habagat. The stable wind direction condition presents a relationship with having higher wind speeds as presented above.

(3) A vertical extrapolation to 20 m and 30 m was calculated using power law and the coefficient α provided from the various pieces of literature. An increase of 30% was observed as height increased from 10 m to 30 m. (4) The maximum power density value for Bagasbas Daet is 109.1 W/m^2 and 196.2 W/m^2, at heights of 10 m and 30 m, respectively. The annual average wind power density is 52.7 W/m^2. Hence, the region is considered to have a low wind energy potential.

(5) Five variations of the AEOLOS three-bladed horizontal axis wind turbines (3 kW, 5 kW, 10 kW, 10 kW, and 20 kW) were considered. The turbine with the highest annual energy potential was from the 20 kW wind turbine.

(6) Among the five wind turbines, the most efficient in terms of capacity factor is the 5 kW AEOLOS-V wind turbine.

(7) As compared to other renewable energy resources, the sustainability of the solar installation was more adoptive for the low carbon approach [29] when the solar abundance was present, but in the present situation for Barangay Bagasbas, the installation of a wind turbine was more accepted. Other accepted renewable resource for the Barangay Bagasbas was the energy conversion of waste plastic by the way of the pyrolysis process, which is sustainable [28].

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