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DETERMINATION OF A POTENTIAL FOR THE INSTALLATION OF SMALL-SCALE WIND TURBINE IN BARANGAY BAGASBAS, DAET CAMARINES NORTE, PHILIPPINES

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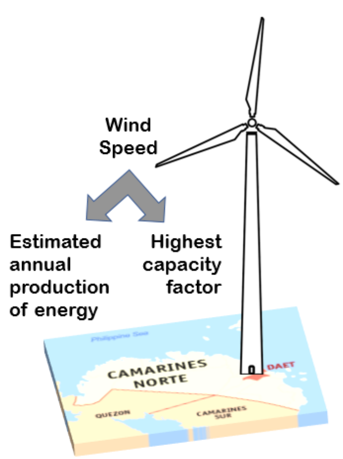
Graphical abstract



Abstract

The wind characteristics in Barangay Bagasbas Daet, Camarines Norte, by way of 5-year win data at a 10-m elevation was analyzed using the data gathered from PAGASA or the Philippine Atmospheric Geophysical and Astronomical Services Administration. The area has an overall mean wind speed of 3.36 m/s at 75 degrees North of East. By way of Weibull model to fit the wind data distribution recording an annual wind density of 52.94 W/m2. Power curves used for the estimate of the annual generated energy are 3 KW(V), 5 KW(V), 10 KW(V), 10 KW(H) and 20 KW(H) for small-scale turbine. A value of about 17,095.23 kWh/year was expected for the annual production of energy for 20 KW(H) wind turbine. However, the 5 kW(V) wind turbine shows the highest capacity factor of 13.97%.

Keywords: Bagasbas, Daet, wind assessment, wind energy, weibull

1.0 INTRODUCTION

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

When this turbine was sized properly it can offer a dependable source of energy for developing countries [2]. Studies have been conducted in the evaluation of a possible potential regarding the energy value for wind to be used in wind turbines for small-scale. Wind speed characterization of the region of Incek in Ankara, Turkey was studied using data coming from wind generated at 20m and 30m heights. A 1 min average value data was generated over a 1 year period starting June 2012 up to June 2013. Results showed a power density in its maximum of about 98 (W/m²) encountered during the month of March. Small scale wind turbine performance was investigated and was found capable of providing an average household for a year in Turkey [3]. Chandel et al., [4] revealed the potential of wind energy in the western Himalayan region at 1 min, 10 min, per hr and with a per day interval. Furthermore, vertical wind profiles at different height hubs were also determined.

Results showed that the speed of the wind ranged from 1 to 16m/s all throughout the year, making the location a potential for a wind energy system in a small-scale that can bring up to 4 KWp with minimum wind cut speeds from 1.5-2.5m/s. The statistical characteristic in Alicante province, Spain by measuring the wind speed was determined using a wind data for 9-year generated at 2m [5]. Result showed about 1.7 m/s overall wind speed with its maximum during the day in spring-summer season while a record at night during autumn-winter season to be its least. Wind frequency distribution showed a calm hrs to be high and observed a multimodal pattern. This was modelled using the sum of log normal, giving a good fit with an $r^2 > 0.99$. The potential use of small-scale turbines in the area is limited, hence hybrid systems were recommended.

Farhan et al. [6] analyzed the potential of harvesting the energy of wind in one site in the south part region of Pakistan. At four different altitudes with wind power showing individual wind power densities and frequency distribution can be generated through calculation in a commercial wind turbine. Weibull parameters were calculated by way of 5 methods used numerically. Results showed that about 6.172 m/s of mean wind speed annually while the power density value was about 310 W/m^2 at elevation of 80m showing high density of power during the months of April and in August. A projected electricity cost per KWh of about 0.0263 US$/kWh making the site a possible location for the installation of small-scale systems.

In the Philippines by 2030, a target increase of 200% in renewable energy capacity, with 2500 MW wind power production. Countrywide evaluation for the potential of wind energy was done but little to no research was conducted in the assessment of the country's potential for wind resource using a small-scale system. 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/m^2 [7]. It was noted that elevation, proximity and latitude to coastline was the prime consideration on the Philippines wind resource in which the north and northeast were seen to be the best while south and south west to be the worst. Tagum et al. [8] conducted continuous wind measurement and monitoring to establish wind patterns and determine in the northeast of Luzon in the Philippines the potential of enough wind energy. 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 from east and southwest were calculated respectively.

The main goal of this research study is by determining the possible potential of the location of Barangay Bagasbas Daet, Camarines Norte regarding wind energy but focusing on small-scale wind turbine applications.

2.0 METHODOLOGY

Analysis of Meteorological Data

Overview of Barangay Bagasbas, Daet, Camarines Norte and data source

The Philippines, as shown in Figure 1(a), is an archipelago consisting of 7,641 islands and situated in the middle of the West Philippine Sea (formerly known as South China Sea) and the Pacific Ocean. The average temperature annually is 26.65 °C, making January the coldest while May the hottest month with approximate mean with respect to temperatures of 26.65 °C and 28.4 °C, respectively. With regards to the relative humidity, March has 71% and September has an 85% average month record, while the mean rainfall per year is observed from 965 mm to 4064mm. The country's climate was only (1) the rainy season, from May up to October; and (2) the dry season, starting from November up to April.

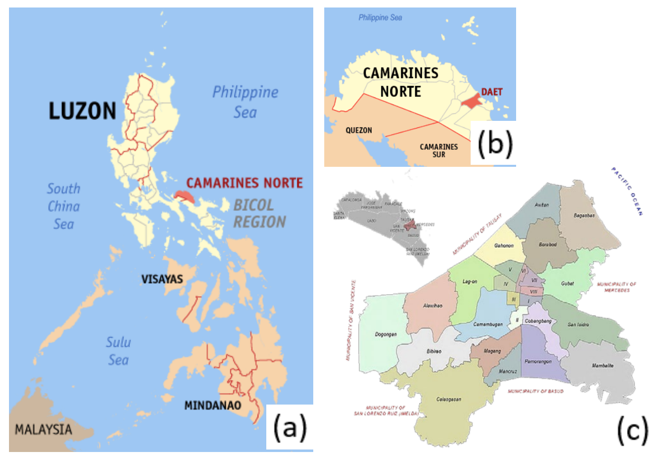


Figure 1 (a) Map of the Philippines showing the Camarines Norte region, (b) Map of Camarines Norte showing the municipality of Daet, and (c) A photograph of the PAGASA weather station in Daet.

On the other hand, Daet is a first-class municipality and the capital of the province of Camarines Norte from the Bicol Region as can be seen in Figure 1(b). It has a coordinate of 14 08' 18'' (latitude) and 122 58' 46" (longitude). Daet has a total land area of 72,483 hectares with 0-8% slope and is generally considered as flat due to its location near the coastal area. Figure 1(c) shows the 25 Barangays of Daet with a population of 104,799 people as of 2015. Barangay Bagasbas in Daet was considered by the Department of Tourism as a surfing spot owing to its windy environment; hence the area of interest for the study. The main electricity source of the region is geothermal energy. However, the supply is unreliable and frequent black-outs occur in the area. Thus, the study for another possible source of electricity is needed.

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. Wind data recorded every 3 hours for a 5-year period from 2012 to 2016 was collected and statistically analyzed. Figure 2(a) shows a photograph of the PAGASA Daet Station and Figure 2(b) 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 Daet, Camarines Norte PAGASA Weather Station

Table 1 Nominal specifications of the equipment used in the study

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

The pattern of wind speed and direction

Results on monthly average wind speed at 10-m above the ground from the five-year data are shown in Figure 3. The highest monthly average wind speed occurred in January with 4.55 m/s, while the lowest occurred in May at 2.47 m/s. The yearly average value of the speed of the wind was 3.35 m/s. In the dry season (November-April), the speed of the wind was relatively higher than the wet season (May-October). Figure 4 displays 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 in the dry season while in the lowest occurred value was averaging at 5 am with 2.10 m/s wind speed during the wet season.

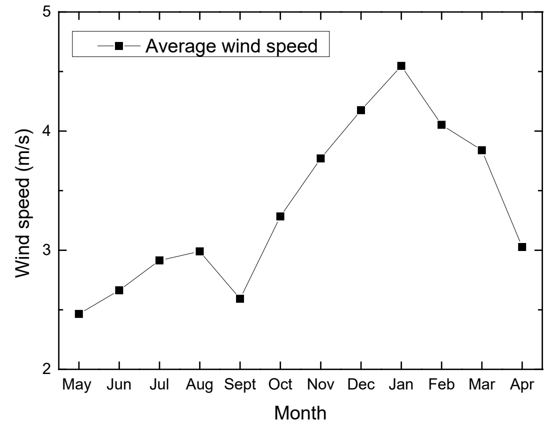


Figure3 Monthly average wind speed of Daet for 2012-2016

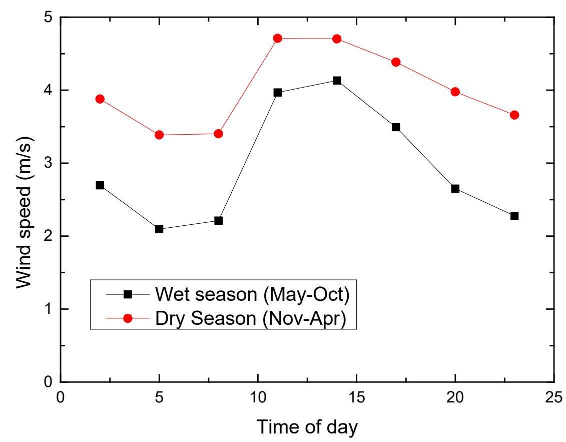


Figure 4 Diurnal evolution of wind speed throughout the day

One of the significant things that should be noticed is by determining the direction of the wind. Figure 5 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 for the dry season.

Parameters determined using Weibull

Wind speed on-site data measurements are recorded between 1min, 10-min, and per hour steps by way of the probability distribution for wind speed characterization. The two statistical analyses were done by the use of Weibull and log-norm distribution [9] and gives a good fit. Furthermore, Islam et al. [10] discussed that by simplicity in calculating a wind resource, a

Weibull distribution function can be used. While Cabello et al., [5] do not recommend using Weibull distribution for high frequency

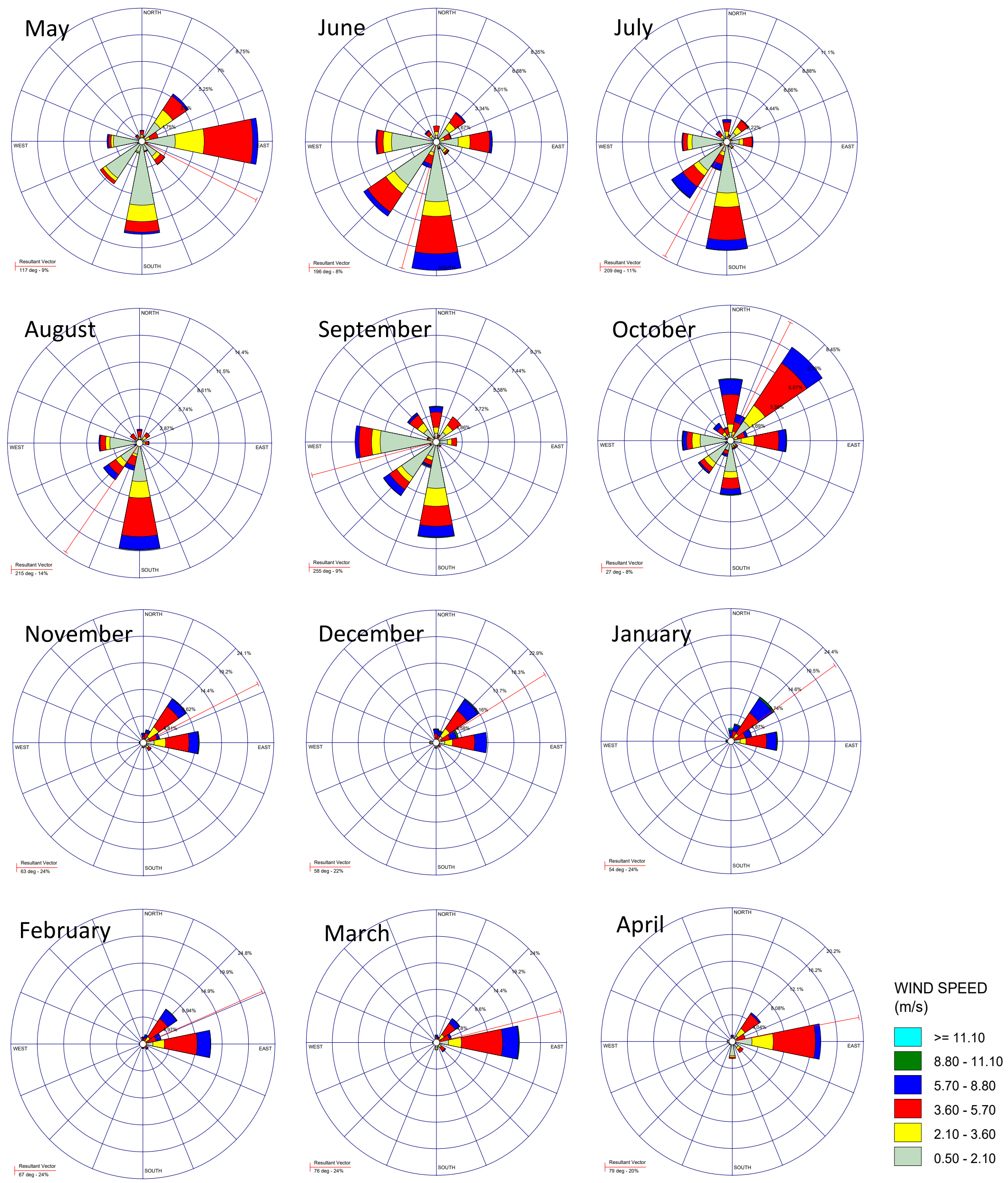


Figure 5 Monthly wind rose diagrams for wind direction

or modality. Two parameter functions that can be worked for is the determination of a probable wind speed. A probability density function will be useful where an area for wind speed is under investigation, while the use of cumulative distribution function will assess an area for potential on the use of turbine [10].

The probability density together with the cumulative distribution function was solved in the following Equations (1) and (2), respectively [3], [6], [10], [11].

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

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

where *v* is the value of wind speed, k for shape parameter and c for shape parameter.

Chang et al. [12], Farhan et al [6] and Islam et al.[10] reviewed the six kinds of numerical techniques and found out that the empirical method was inclined to large datasets and possessed better fitting results for the measurement and assessment data for wind energy potential. In this paper, the researchers used estimation was by way of empirical method by using the parameters of Weibull.

Empirical method involves the wind mean speed ($\bar{v}$) and speed standard deviation data (σ), defined as Equations (3) and (4), respectively [13];

$$\bar{v} = \frac{1}{n}\sum_{i=1}^{n} v_i \quad (3)$$

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

The shape *(k)* and scale *(c)* parameter can be investigated in the following equation [14]:

$$k = (\frac{\sigma}{\bar{v}})^{-1.086}, (1 \leq k \leq 10) \quad (5)$$

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

$\Gamma(x)$ is the gamma function which is expressed as [15]:

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

RMSE was also calculated using the following equation:

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(f^*(v_1) - f(v_1)^2\right]^{\frac{1}{2}} \quad (8)$$

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

The average wind speed, calculated shape parameter *(k)* and also the scale parameters *(c)* as shown in the Table 2. The low value of *RMSE* shows that the empirical method can be a valuable method for the determination of the Weibull parameters is satisfactory for the region under the study. Figure 6 illustrates the wind speed values as observed in every monthly probability density function as well as the Weibull distribution.

Table 2 Monthly Average Wind Speed and Weibull Parameters at 10 m Height

Months Observed	10 m			
	Ave. wind speed (m/s)	*k*	*c* (m/s)	*RMSE*
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
May	2.47	1.783	2.775	0.004

Extrapolating the Wind Speed Vertically

The value of the wind speed was directly proportional to the vertical height, hence an adjustment in the wind speed was recorded according to its vertical height. Justus and Mikhail [16] discussed the importance of having thorough project height variations in its probability distribution. Extrapolation of the gathered wind data to the given hub height by way of 1/7th of the wind power law or can also use the wind shear factor or coefficient (α). Rehman and Al-Abbadi [17] noted that the energy production, as well as the plant capacity factor, was in accordance with the wind shear coefficients. 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 wind profile are currently being used, either as based on experience or mathematical models like power law, logarithmic law, and numerical models. In this study, the power law is utilized and is described in Equation (9) [18],

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

where v_1 (m/s) to be rated value of wind speed at position heights h_1 (m), v_2 (m/s) to be the rated value of wind speed at height h_2 (m), and α indicates the power law exponent or exponent of wind shear from the following equation:

$$\alpha = (0.37 - 0.0881\, lnV_2)/(1 - 0.0881\ln(h_2/10)) \quad (10)$$

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

Table 3 Monthly Average Wind Speeds for the Observed Data at 10m and Extrapolated Data at 20m and 30m Height

	Average wind speed (m/s)		
Month Observed	**10m**	**20m**	**30m**
June	2.66	3.17	3.48
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
May	2.47	2.95	3.24

Table 4 Seasonal Average Wind Speed for 10m, 20m and 30m

Season	Average wind speed (m/s)		
	10m	**20m**	**30m**
Wet	2.81	3.33	3.65
Dry	3.90	4.55	4.94

Wind Energy Assessment in Daet

Wind power density

It is an energy in an area per unit time and is considered as a representation of wind energy potential of a certain region [20]. Wind power density was defined in Equation (11),

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

where ρ the standard density of air at sea level (t=15°C) and 1 atm pressure and $\bar{v}$ for the observed wind speed mean in (m/s).

The important value in estimating the wind energy are the most probable speed of wind (v_{mp}) and maximum energy wind carrying speed $(v_{max,E})$ [4]. Their respective values through Weibull parameters as described in Equations (12) and (13) [19],

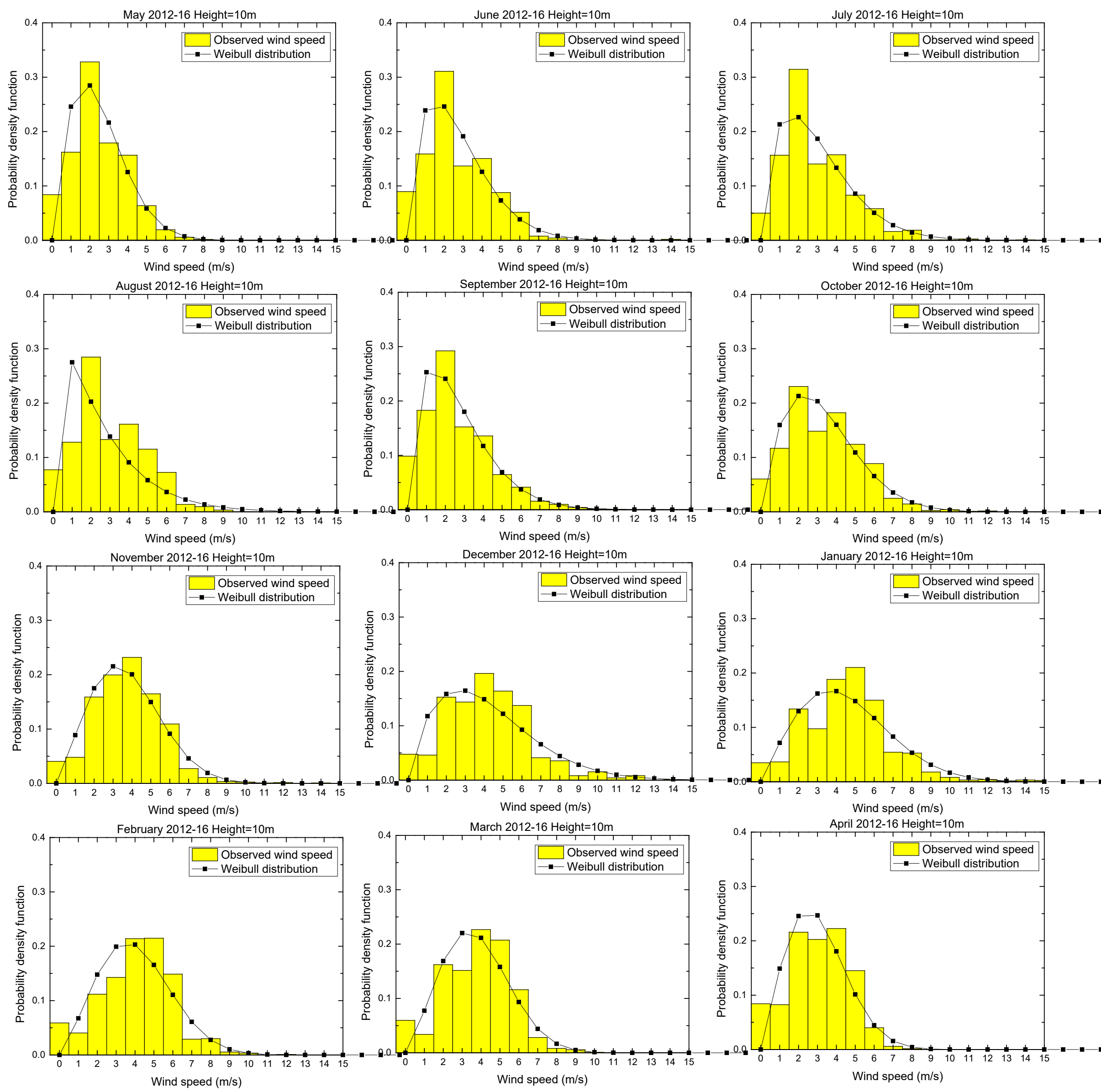


Figure 6 Monthly probability density function

Table 5 Weibull Parameters for Monthly Wind Speed Values

Month	10m			20m			30m		
	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

Table 6 Weibull Parameters for Seasonal Wind Speed Values

	10m			20m			30m		
Season	*k*	*c*	*RMSE*	*k*	*c*	*RMSE*	*k*	*c*	*RMSE*
Wet	1.579	3.142	0.002	1.673	3.740	0.003	1.726	4.104	0.007
Dry	1.939	4.387	0.001	2.066	5.127	0.002	2.137	5.571	0.006

Table 7 Wind Speed Values for 12 months Showing v_{mp} and v_{max}

	10m		20m		30m	
Month Observed	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)
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
May	1.749	4.231	2.211	4.897	2.501	5.297

Table 8 Wind Speed Values for 2 Seasons Showing v_{mp} and v_{max}

	10m		20m		30m	
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

Table 9 Values for Wind Power and Energy Density in 12 Months

	10m		20m		30m	
Month Observed	*P* (W/m^2)	*E* (kWh/m^2)	*P* (W/m^2)	*E* (kWh/m^2)	*P* (W/m^2)	*E* (kWh/m^2)
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	105.19	78.259	149.750	111.414	181.743	135.217
January	109.07	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
May	19.931	14.829	32.166	23.932	41.585	30.939

Table 10 Values for Wind Power and Energy Density for Two Seasons

	10m		20m		30m	
Season	***P*** **(W/m²)**	***E*** **(kWh/m²)**	***P*** **(W/m²)**	***E*** **(kWh/m²)**	***P*** **(W/m²)**	***E*** **(kWh/m²)**
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

$$V_{mp} = c\left(1 - \frac{1}{k}\right)^{\frac{1}{k}} \quad (12)$$

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

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 probable occurred in January and in dry season, while the minimum wind speed probable occurred in September and in wet season. Wind power density will be determined using the method of distribution in Weibull probability described in Equation (14) [20].

$$\overline{P} = \int_0^\infty \frac{1}{2}\rho v^3 f(v)dv = \frac{1}{2}\rho c^3 \Gamma(1 + \frac{3}{k}) \quad (14)$$

The important wind energy density *(E)* can be solved in multiplying the value of wind power density by the desired time *(T)* in hours as given by Equation (15).

$$E = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right)T \quad (15)$$

The wind power density and the energy values that were calculated at 10m, 20m, and 30m heights are shown in Table 9 and Table 10. Values of power density were highest in dry season while January to be for all the heights. The generated potential wind energy in the site was classified based on the average power density amount shown in Table 11. The maximum wind power density value for Daet is 109.1 W/m² in January at 10m and 196.2 W/m² at 30m. While the calculated yearly wind average power density is 52.7 W/m². Thus, the region can be classified as in the range of power class 1, which shows low potential for wind energy. This can be further utilized in small-scale wind turbines.

Table 11 Wind Power Classification [22]

Power class	Power density at 10m (W/m²)	Power density at 30m (W/m²)
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

Table 12 Small-scale Wind Turbines Selected with its Characteristics

AEOLOS	V 3kW	V 5kW	V 10kW	H 10kW	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 (m²)	8.04	12.57	19.63	32.17	50.27

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 and characteristics of the AEOLOS three bladed horizontal axis wind turbines were selected as shown in Table 12. The given five turbines were chosen based on the value of their very low cut-in and rated speed, for the achievement of a more energy. The power curves for the five turbines were shown in Figure 7.

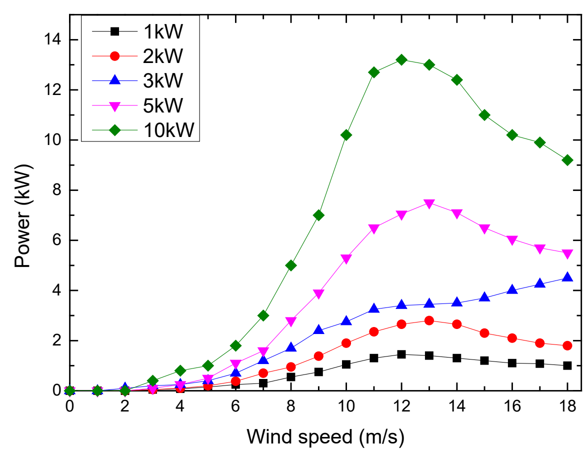


Figure 7 Power Curves for the Selected Wind Turbines

The turbine hub heights were assessed according to the manufacturer's specifications. Since the hub heights are different from the initial extrapolated values which is 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 Equations (16) and (17), respectively, as shown below:

Occurrence time in *(h)* = *f (V)* x 8760 *h* (16)

$$Pw = \sum(P(V)x\, f(V)x\, 8760) \quad (17)$$

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

The wind turbine capacity factor (C_f) is the ratio of its actual output per unit of time. When the annual capacity factor of a turbine is 17% or over, it is considered to be desirable. Wind energy cost can be assessed, through such methods that will liken the adaptability of the system in certain location for installation. These factors can be categorized if the system is viable through the manner how much its maintenance, operation, and investment cost [22].

In determining the energy cost of the turbine produced in KWh, the present value of cost *(PVC)* was determined. The present value of cost was also determined by way of the following assumptions: [22, 23, 24]

- The cost calculated was established in method used in determining its present value
- A lifespan of 20 years for the machine
- Inflation rate *(i)* is 3.2%, while for the interest rate *(r)* is 3%. [25]
- Operational, maintenance and the repair cost *(COMR)* are assumed 25% of the yearly cost of the machine (machine price/lifespan).
- A 10% salvage value was taken into account for the investment in civil and machine works
- Investment cost *I* that comprise the turbine price in addition of 20% civil works plus the connections cables for the grid and other cost of setup.
- Using above assumptions, the equation for the cost of present value *PVC* is:

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

Where:
I for the investment cost
COMR for the operational, maintenance and repair cost
i for the inflation rate,
r for the interest rate,
n for the lifetime of the machine (in years) and
S for the salvage value.

The unit cost of energy *(CPU)* can be calculated by dividing the Present Value Cost *(PVC)* to the total generated energy to the entire lifespan of the wind turbine [26].

Table 13 Turbine Cost, Present Value of Cost, Annual Energy Production, Capacity factor and Cost analysis (CPU) for the Chosen Wind Turbines

Turbine Size	Hub height (m)	Turbine Cost (USD)	*PVC* (USD)	*AEP* (kWh)	C_f (%)	*CPU* (c$/kWh)
3kW (V)	9	1672	1822	3494.58	13.3	0.52
5kW (V)	12	3300	3576	6118.11	13.97	0.58
10kW (V)	12	6515	7041	6985.96	7.97	1.0
10kW (H)	18	10700	11551	10014.71	11.43	1.15
20kW (H)	18	27420	29569	17095.23	9.76	1.73

Using cost analysis in Table 13, 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 5kW is better at 13.97% with CPU of 0.58 c$/kWh.

4.0 CONCLUSION

In this research paper, a 5-year wind speed data recorded in a 3-hour interval at Bagasbas Daet, Camarines Norte has been statistically analyzed using the Weibull probability distribution function. Its significant study results are reviewed below:

1. The highest monthly average wind speed occurs during January at 4.55 m/s, and the lowest occurred during May at 2.47 m/s. The annual average wind speed is 3.35m/s.
2. 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 is solved using power law and the coefficient α provided from literature. An increase of 30% was observed as height increased from 10 m to 30 m.
4. Maximum power density value for Bagasbas Daet is 109.1 W/m^2 and 196.2 W/m^2, at heights 10 m and 30 m respectively. Yearly average wind power density was 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 (3kW, 5kW, 10kW, 10kW and 20kW) 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 C_f is the 5kW AEOLOS-V wind turbine.

The authors recommend the Barangay Bagasbas area to provide other means of developing a sustainable electricity source other than wind, like converting their wastes as an alternative fuel source [27, 28] or by doing some energy audit to lessen electricity consumption [29].

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