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Wind Speed and Power Density Analysis for Sustainable Energy in Batouri, East Region of Cameroon

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Abstract

This paper develops the modeling of wind speed by Weibull distribution in the intention to evaluate wind energy potential and help for designing small wind energy plant in Batouri in Cameroon. The Weibull distribution model was developed using wind speed data collected from a metrological station at the small Airport of Batouri. Four numerical methods (Moment method, Graphical method, Empirical method and Energy pattern factor method) were used to estimate weibull parameters *K* and *C*. The application of these four methods is effective using a sample wind speed data set. With some statistical analysis, a comparison of the accuracy of each method is also performed. The study helps to determine that Energy pattern factor method is the most effective ($K = 3.8262$ and $C = 2.4659$).

Keywords

Weibull Distribution, Mean Wind Speed, Statistical Tests, Wind Energy

1. Introduction

The Sustainable Development Agenda is a comprehensive plan of action for humanity, the planet and prosperity, which also aims to strengthen peace around the world. The Sustainable Development is a global call to action to end poverty, protect the earth's environment and climate, and ensure that people everywhere can enjoy peace and prosperity. Renewable energy sources play a vital role in securing sustainable energy with lower emissions [1] [2]. It is already accepted that renewable energy technologies might significantly cover the electricity demand and reduce emissions. Then, for the last fifteen years, the world has enjoyed renewables generation capacity increases in a double-digit Terawatt-hours range. Although renewables consumption is fast developing in Asia Pacific, Europe and North America, significant coordination efforts are required among stakeholders in sub-Saharan Africans countries such as Cameroon. According to the World Bank, 91% of Cameroon's urban households had access to electricity in 2016, while in rural areas 21% of households had access [1] [3] [4]. Moreover, those of Cameroonians with access experience a lot of severe internal cuts (shedding) of electricity. In order to better respond to these deficits and for a better efficiency of its energy system, Cameroon must develop several other energies, in particular those from renewable sources such as: solar, biomass, micro hydro, wind [4] [5] [6]. That is why the State of Cameroon promotes the development of renewables energies, of which wind energy can be an important component. In that situation for this country, it is relevant to study and bring out the results in order to help all project of production of electricity from renewable sources. Indeed, according to data published by the Eastern Regional Water and Energy Delegation in October 2019, the rate of access to electricity in the region is estimated at 17.35%. On the 1331 localities in the region, only 239 are electrified [7] [8].

This study aims to estimate the potential of wind energy in the town of Batouri in the East Region of Cameroon. Since the choice and optimal sizing of the appropriate wind turbines for the region of interest depend on a good knowledge of wind speed distribution. For this purpose, the average hourly wind speed data for the period of April 2014 to May 2016 provided by a station located at a height of 10 m in Batouri were used. Weibull distribution with four numerical methods to estimate to estimate the Weibull shape (K) and scale (C) parameters will be used in the analysis. An estimation of the wind density energy will be made afterwards [1] [9] [10].

2. Materials and Methods

2.1. Site of Study

Batouri is the town head quarter of the Kadey division in the East Region of Cameroon. It is the second largest municipality in the province after the regional capital Bertoua. It is located on the main (though unpaved) road connecting Bertoua to the Central African Republic. Batouri is at Latitude N at 4˚26' and Longitude E at 14˚43'. **Figure 1** presents Cameroon's map with the location of Batouri [2].

2.2. Materials and Data

Data used for this study has been collected and analyzed by using lots of materials belonging to the Center of Research on Renewable Energy (CRER) of Institute for Geological and Mining Research (IRGM). A weather vane and anemometer installed at a height of 10 meters above the ground, a sensor station and data recovery console, a computer and software Weather link are materials used

Figure 1. Cameroon's map with the location of Batouri.

for this study. Matlab software has been used for numerical equation resolution. Wind speed data used was collected during two years and two months with a step of 30 minutes (period from April 2014 to May 2016). Some wind speed data are available in time series format, in which each data point represents either an average wind speed over a time period of 30 min. The frequency distribution of wind speed measured has been classified for an amplitude of 0.2 (the first one being 0 - 1.2 to avoid the very small speed) of wind speed from data collected on the study period.

2.3. Weibull Distribution

The Weibull distribution is a continuous probability distribution that can fit an extensive range of distribution shapes. Like the normal distribution, the Weibull distribution describes the probabilities associated with continuous data. However, unlike the normal distribution, it can also model skewed data. In fact, its extreme flexibility allows it to model both left- and right-skewed data. The Weibull distribution provides a close approximation to the probability laws of many natural phenomena. It has been used to represent wind speed distribution for application in wind load studies for some time. The Weibull distribution function, has two parameters function K and C. The formula for the probability density function of the general Weibull distribution (the probability density function of wind speed v) is:

$$f(v) = \frac{K}{C} \times \left(\frac{v}{C}\right)^{K-1} \times \exp\left(-\left(\frac{v}{C}\right)^{K}\right) \tag{1}$$

where: v is the wind speed (m/s).

C is the Weibull scale parameter (m/s).

K is the Weibull shape parameter.

The cumulative distribution function of the velocity v is the integral of the probability density function. Thus,

$$F(v) = \int_0^\infty f(v)\mathrm{d}v = 1 - \exp\left(-\left(\frac{v}{C}\right)^K\right) \tag{2}$$

The average wind velocity of a regime, following the Weibull distribution is given by:

$$v_m = \int_0^\infty f(v) \times v\mathrm{d}v \tag{3}$$

Upon substituting Equation (1) and considering the standard gamma function ($\Gamma_n = \int_0^\infty \exp(-x) \cdot x^{\frac{1}{K}} \mathrm{d}x$), we deduce:

$$V_m = C \times \Gamma\left(1 + \frac{1}{K}\right) \tag{4}$$

The distribution of Weibull is suitable for the description of statistics properties of wind. There are common methods for determining parameters K and C as: Graphical method, Empirical method, Energy pattern factor method, Moment method, Equivalent energy Method, [1] [3] [11] [12].

3. Determination of Weibull Parameters

3.1. Numerical Methods

Five methods used to estimate the parameters of the Weibull wind speed distribution are presented below.

3.1.1. Graphical Method

The graphical method is achieved through the cumulative distribution function. In this distribution method, the wind speed data are interpolated by a straight line, using the concept of least squares regression [13] [14] [15]. By converting the Equation (2) into logarithmic form, the following equation is obtained:

$$\ln\left[-\ln\left(1 - F(v)\right)\right] = K \times \ln(v) - K \times \ln C \tag{5}$$

A plot of $\ln\left[-\ln\left(1 - F(v)\right)\right]$ against $\ln(v)$ gives a straight line with K as the slope and ($K \times \ln C$) as the intercept along the vertical axis.

3.1.2. Empirical Method

The Empirical method is defined by using average wind speed and standard deviation by following equations [16]:

$$K = \left(\frac{\sigma}{\overline{v}}\right)^{-1.089} \tag{6}$$

$$C = \frac{\overline{v}}{\Gamma\left(1 + \frac{1}{K}\right)} \tag{7}$$

$$\sigma = \left[\frac{1}{N-1} \sum_{i=1}^{n} \left(v_i - \bar{v} \right)^2 \right]^{1/2} \tag{8}$$

where: $\bar{v}$ is the mean wind speed (m/s);

σ is the standard deviation of the observed data (m/s).

3.1.3. Energy Pattern Factor Method

The energy pattern factor method is related to the averaged data of wind speed and is defined by the following equations:

$$E_{pf} = \frac{\overline{v^3}}{\bar{v}^3} \tag{9}$$

$$K = 1 + \frac{3.69}{\left(E_{pf} \right)^2} \tag{10}$$

$$\bar{v} = C\Gamma\left(1 + \frac{1}{K} \right) \tag{11}$$

(9) Can be solved numerically or approximately by power density technique using (10) [16].

3.1.4. Moment Method

In the moment method, the parameters K and C are determined by the following equations:

$$\bar{v} = c\Gamma\left(1 + \frac{1}{k} \right) \tag{12}$$

$$\sigma = c\left[\Gamma\left(1 + \frac{2}{k} \right) - \Gamma^2\left(1 + \frac{1}{k} \right) \right]^{1/2} \tag{13}$$

where, $\bar{v}$ and σ are the mean wind speed the standard deviation of the observed data of the wind speed, respectively [17].

3.1.5. Equivalent Energy Method

In the equivalent energy method, the parameters k and c are determined using the equations below (14)

$$\sum_{i=1}^{n} \left[W_{vi} - \mathrm{e}^{-\left\{ \frac{(v_i - 1)\left[\Gamma\left(1 + \frac{3}{k} \right) \right]^{\frac{1}{3}}}{\left(v_m^3 \right)^{\frac{1}{3}}} \right\}^k} + \mathrm{e}^{-\left\{ \frac{v_i\left[\Gamma\left(1 + \frac{3}{k} \right) \right]^{\frac{1}{3}}}{\left(v_m^3 \right)^{\frac{1}{3}}} \right\}^k} \right]^2 = \sum_{i=1}^{n} \left(\varepsilon_{vi} \right)^2 \tag{14}$$

$$c = \left[\frac{v_m^3}{\Gamma\left(1 + \frac{3}{k} \right)} \right]^{\frac{1}{3}} \tag{15}$$

where W_{vi}, v_m^3 and ε_{vi} are respectively observed frequency of the wind speed, the mean of cubic wind speed, and error of the approximation [18] [19].

3.2. Performance Model

There are lots of tests which can be used to analyze the accuracy of the methods estimation of parameters. In this study, root mean square error (*RMSE*) and the correlation coefficient R^2 have been used from the following equations:

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}\left(y_i - x_i\right)^2\right)^{\frac{1}{2}} \tag{16}$$

$$R^2 = \frac{\sum_{i=1}^{N}\left(y_i - z\right)^2 - \sum_{i=1}^{N}\left(y_i - x_i\right)^2}{\sum_{i=1}^{N}\left(y_i - z_i\right)^2} \tag{17}$$

where: N is the number of observations, y_i is the actual data, x_i is the predicted data of Weibull distribution, z_i is the mean wind speed [1] [19].

3.3. Wind Energy Density

The main components that determine the wind energy potential of a site are the energy density and the energy available in the wind regime over some period of time. The available power in the wind flowing at mean speed v through a wind rotor blade with sweep area A at any given site can be estimated as [19] [20] [21]:

$$P(v) = \frac{1}{2}\times\rho\times A\times v^3 \tag{18}$$

where: ρ (kg/m^3) is the volumic mass of air.

Then, the power in the wind per unit of area is:

$$P_D(v) = \frac{1}{2}\times\rho\times v^3 \tag{19}$$

Using expression (19) with the Weibull probability distribution the wind energy density of a site expressed as,

$$E_D = \int_0^{\infty} P_D(v)\times f(v)\times \mathrm{d}v \tag{20}$$

Using Equations (1), (4) and (19), Equation (20) simplifies to,

$$E_D = \frac{\rho\times C^3}{2}\times\frac{3}{K}\times\Gamma\left(\frac{3}{K}\right) \tag{21}$$

4. Results and Discussions

4.1. Results

Table 1 presents the mean wind speed from data.

The Weilbull distribution of the years 2014 2015 and 2016 are respectively represented by Figures 2-4, described by its probability function $f(v)$, versus the mean wind speed.

Tables 2-4 show the statistical analysis results.

Table 5 presents a global rank of numerical methods performance. It is important to note that only one column was enough to rank the method, since the three criteria (*RMSE*, X^2 and R^2) gave the same results.

Table 1. Mean wind speed.

Years	Months	Monthly mean wind speed (m/s)
2014	April	2.18
	May	2.13
	June	2.03
	July	2.17
	August	2.24
	September	1.95
	October	1.94
	November	2.28
	December	2.57
	2014	**2.17**
2015	January	2.65
	February	2.50
	March	2.35
	April	2.07
	May	2.03
	June	2.04
	July	2.11
	August	2.15
	September	1.98
	October	1.97
	November	2.21
	December	2.57
	2015	**2.22**
2016	January	2.60
	February	2.60
	March	1.65
	April	1.87
	May	2.14
	2016	**2.17**

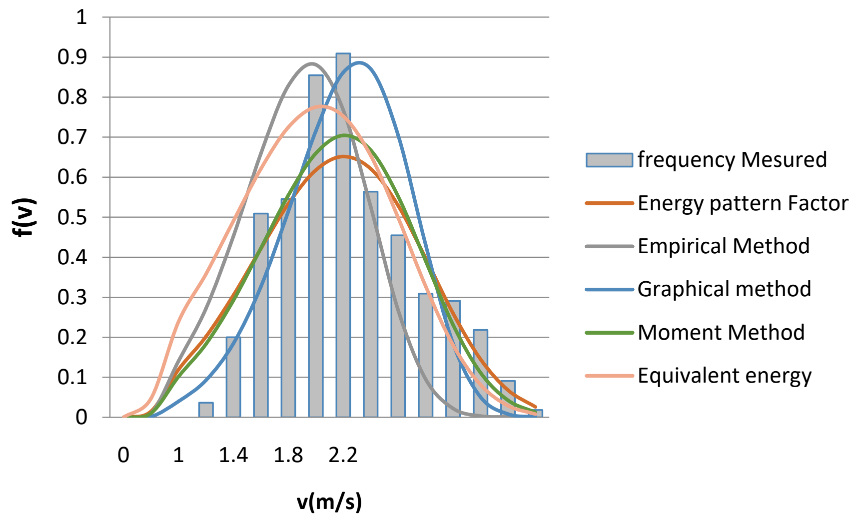

Figure 2. Distribution of Weibull function and frequency measured, year 2014.

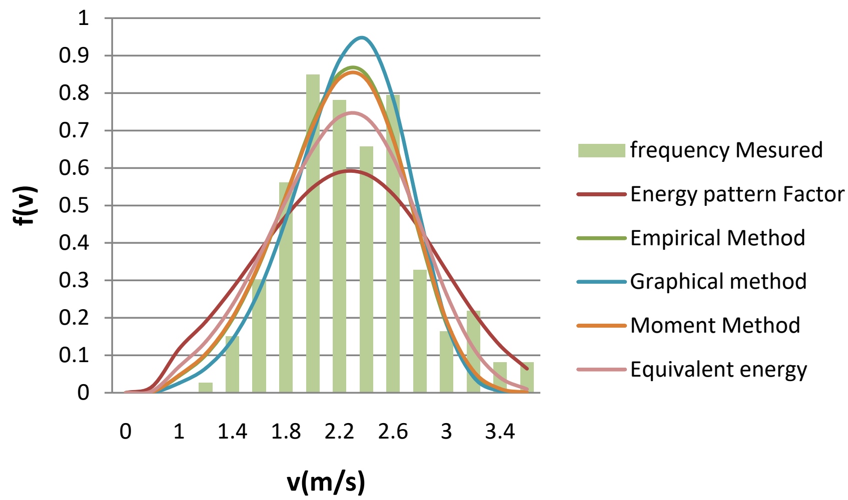

Figure 3. Distribution of Weibull function and frequency measured, year 2015.

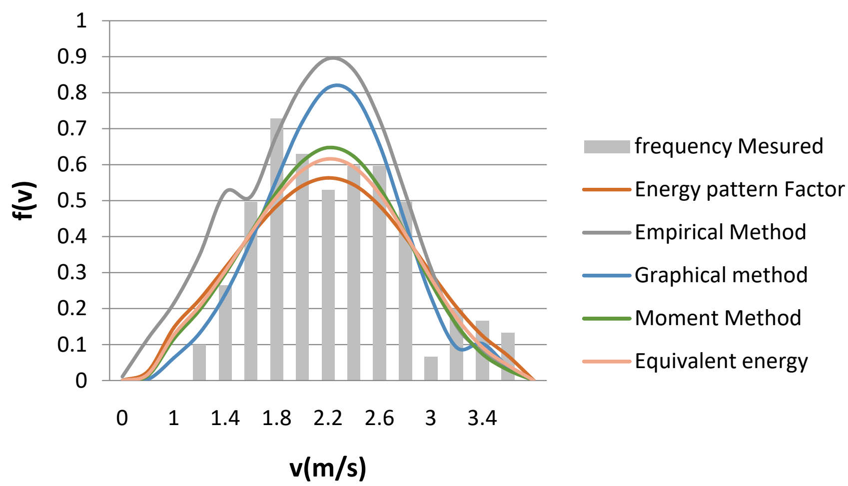

Figure 4. Distribution of Weibull function and frequency measured, year 2016.

Table 2. Weibull parameters and statistical analysis, year 2014.

Numerical Methods	Weibull parameters		Statistical tests		
	K	*C*	R^2	X^2	*RMSE*
Empirical method	4.8434	2.0642	0.96583	0.00072	0.02536
Graphical method	5.6785	2.3923	0.9655	0.00322	0.05360
Energy pattern factor	4.0563	2.3682	0.95284	0.00218	0.04414
Moment method	4.6525	2.3356	0.93480	0.00240	0.04632
Equivalent Energy	4.3767	2.3493	0.92692	0.00338	0.05495

Table 3. Weibull parameters and statistical analysis, year 2015.

Numerical Methods	Weibull parameters		Statistical tests		
	K	*C*	R^2	X^2	*RMSE*
Empirical method	5.5422	2.3273	0.97030	0.00095	0.03031
Graphical method	6.1696	2.4259	0.9739	0.00105	0.03495
Energy pattern factor	3.8262	2.4659	0.9857	0.00060	0.02404
Moment method	5.4563	2.3842	0.9709	0.00093	0.03000
Equivalent Energy	4.7866	2.4100	0.9753	0.00079	0.02764

Table 4. Weibull parameters and statistical analysis, year 2016.

Numerical Methods	Weibull parameters		Statistical tests		
	K	*C*	R^2	X^2	*RMSE*
Empirical method	4.2538	2.3734	0.9184	0.00341	0.05647
Graphical method	5.1770	2.3373	0.9418	0.00244	0.04770
Energy pattern factor	3.5499	2.4234	0.9758	0.00142	0.03642
Moment method	4.0629	2.3850	0.9706	0.00172	0.04017
Equivalent Energy	3.8704	2.3980	0.9725	0.00162	0.03886

Table 5. Global rank of statistical performance of numerical methods.

Numerical Methods	R^2	X^2	*RMSE*
Empirical method	1^{st}	5^{th}	5^{th}
Graphical method	2^{nd}	3^{rd}	4^{th}
Energy pattern factor	3^{rd}	1^{st}	1^{st}
Moment method	4^{th}	4^{th}	3^{rd}
Equivalent Energy	5^{th}	2^{nd}	2^{nd}

4.2. Results

Firstly, the statistical analysis presented above shows that the values of the performance tools used namely *RMSE*, X^2, and R^2 are very close to each other whatever the digital method used. In addition, viewing **Figures 2-4** it appears that two of the methods (Energy Pattern Factor and Equivalent Energy) give curves having a better confusion with the frequency histogram of wind speed measured, consequently giving a better approximation of the parameters K and C. Moreover, from the classification table of performance tools it appears that the Energy Pattern Factor methods has the best performance with the rank 3rd, 1st and 1st 3rd respectively for R^2, $RMSE$ and X^2.

Secondly, for each numerical method, according to the modeling of wind speed by weibull distribution, the values of parameter K has some variation. Its value is included between 3.5499 and 6.1696. The values of C are included between 2.0642 to 2.4659.

Finally, since the energy pattern factor method has the best performance mainly for the year, then the best approximation of these parameters can be: $K = 3.8262$ and $C = 2.4659$.

The average wind speed is around 2.3 m/s. Since for a suitable installation of conventional horizontal axis wind turbines whose cut-in velocity is about 4 m/s [1] [21], Batouri is not suitable for wind energy. But this speed cannot be negligible for mainly domestical need as lighting, battery charging, radio, small water pumping etc. Especially in dry season in a locality with the rate of access to electricity estimated at 17.35%.

5. Conclusions

The objective of this study was the modeling of wind speed by Weibull distribution in the intention to evaluate wind energy potential and help for designing small wind energy plant Batouri in Cameroon. A contribution to rural electrification and then to the sustainable development was focus in that area. The Weibull model of wind speed distribution was done through four numerical methods. For each method, the model obtained is effective because all statistical tests showed good performance. The best performance was obtained by energy pattern factor method with parameters $K = 3.8262$ and $C = 2.4659$.

Since the rate of access to electricity in the locality of study is very low, a potential of wind energy with mean wind speed around 2.3 m/s cannot be negligible for domestical need.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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