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Modeling of Characteristics of Wind by Weibull Distribution and Estimation of Wind Energy in Douala, Littoral Region of Cameroon

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ABSTRACT: The objective of this study consists to the modeling and prediction of the regime of windin the intention to estimate the potential of wind energy at Douala in Cameroon. The probability densityof windspeed is modeled through an analysis using the Weibull distribution function. The model has been obtained using wind speed data collected from a metrological station at the Airport of Douala. Four methods for calculating the shape and scale parameters of the Weibull wind speed distribution for wind energy analysis are presented: The Maximum likelihood method, the Graphical method, the Empirical method and the proposed Energy pattern factor method. 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 Empirical method is the most effective (K= 2.80 and C= 1.97).

KEYWORDS: Weibull distribution, Mean wind speed, Statistical tests, wind energy.

I. INTRODUCTION

In Cameroon,the access to electricity in Cameroon was around 49% in 2012.This rate is about 23% in rural areas [1].The energy system is dominated by wood combustible and waste which constitutes a consumption of 77% (with more than 95% used for meal cooking), followed by fossils energy which constitutes 17.3 % and lastly by hydropower constituting 4.9 %. The main source of electricity generation is from hydro (96%) and a very little fraction from oil (4%) [2].

All developed countries have made use of renewable energy sources to make effective their electricity energy systems. Actually, in the same vision, the State of Cameroon promotes renewables energies, of whichwind 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 such as hydropower, solar, biomass, wind….Considering that starting point towards the implementation of a wind energy project in a region, is the thorough understanding of the prevalent characteristic wind regimes.

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This study has been done in the intention to estimate the potential of wind energy in the town of Douala in the Littoral Region of Cameroon. The choice and optimal sizing of the appropriate wind turbines for the region of interest depend on a good knowledge of wind speed distribution, from which the energy density of the site can be estimated, is required.
Since variation mean wind speed on a period is hard to predict, wind speed distribution a can be well characterized in terms of the probability density function.This study has been done in the intention to estimate the potential of wind energy in Douala. Base on available data, the Weibull distribution has been used.
This analysis attempts to evaluate and compare four methods for estimating the shape (K) and scale (C) Weibull parameters and adjusting the Weibull distribution of wind speeds inDouala. Finally an estimation of wind density energy will be done.

II. MATERIALS AND METHODS

a. Site of study, materialsand data

The site of study is Douala in the Littoral Region of Cameroon. There are stations installed at the International Airport in the meteorological station site managed by the Agency for the Safety of Air Navigation in Africa and Madagascar (ASECNA). Doualais at an altitude of 13 m, Latitude N at 4˚00'28", Longitude E at 9' 43'09".

Lot of materials has been used such as: 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.Matlab used for some numerical equation resolution.

b. Wind speed data

The data used in this study were collected wind speed for 10 months with a step of 30 minutes (period from November 2011 to August 2012). 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. An example of such data giving over a period of 24 hours is given in the following table I.

Table I: Data of wind speed as measured daily

Hour (h)	Wind Speed (m/s)	Hour (h)	Wind Speed (m/s)	Hour (h)	Wind Speed (m/s)	Hour (h)	Wind Speed (m/s)	Hour (h)	Wind Speed (m/s)	Hour (h)	Wind Speed (m/s)
00:00	0.9	04:00	0.0	08:00	1.8	12:00	2.2	16:00	4.5	20:00	0.9
00:30	1.8	04:30	0.0	08:30	1.3	12:30	2.7	16:30	3.6	20:30	0.0
01:00	1.3	05:00	0.0	09:00	1.8	13:00	3.6	17:00	2.7	21:00	0.4
01:30	0.0	05:30	0.4	09:30	1.8	13:30	3.6	17:30	2.2	21:30	0.4
02:00	0.0	06:00	0.4	10:00	1.8	14:00	4.0	18:00	1.8	22:00	0.9
02:30	0.4	06:30	1.3	10:30	1.3	14:30	4.9	18:30	0.9	22:30	0.9
03:00	0.0	07:00	0.9	11:00	0.9	15:00	5.8	19:00	1.3	23:00	0.4
03:30	0.4	07:30	2.2	11:30	1.3	15:30	4.5	19:30	1.3	23:30	0.4

After the classification for an amplitude of 0.2 (the first class being 0-1.2 to avoid the very small speed) of wind speed from data collected on the study period, the frequencies have been calculated for each class. Then the frequency distribution of these data is summarized in the following tableII.

Table II: The frequency distribution of wind speed measured

Wind speed (m/s)	0-1.2	1.2-1.4	1.4-1.6	1.6-1.8	1.8-2.0	2.0-2.2	2.2-2.4	2.4-2.6	2.6-2.8	2.8-3.0	3.0-3.2
Frequency (%)	7.2	16.8	15.8	20.4	16.4	10.5	4.6	5.6	1.6	0.3	0.7

c. Weibull distribution

The Weibull distribution (named after the Swedish physicist Weibull, who applied it when studying material in tension and fatigue in the 1930s) provides a close approximation to the probability laws of many naturalphenomena. It has been used to represent wind speed distribution for application in wind load studies for some time. In recent years most attention has been focused on this method for wind energy application not only due to its greater flexibility and simplicity but also because it can give a good fit to experimental data. The Weibull distribution function,a two parameter function, for wind speed is expressed mathematically as:

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

Where: (f (V)) is the probability density function of wind speed V
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,

$$F(V) = \int_0^\infty f(V)dV = 1 - exp\left(-\left(\frac{V}{C}\right)^K\right) \quad (2)$$

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

$$V_m = \int_0^\infty f(V) \times V\, dV \quad (3)$$

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

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

The distribution of Weibull is suitable for the description of statistics properties of wind.There are common methods for determining parameters K and C:Graphical method, Empirical method, Maximum likelihood method Energy pattern factor method, Moment method….

d. Determination of Weibull parameters

In this study, for estimating the parameters of the Weibull wind speed distribution, four methods are presented.

i. The maximum likelihood method

The Weibull distribution can be fitted to time series wind data using the maximum likelihood method as suggested by Stevens and Smulders [3]. The shape parameter K and the scale parameter C are estimated using the following twoequations:

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$$K = \left(\frac{(\sum_{i=1}^{n} V_i^k \ln(V_i))}{(\sum_{i=1}^{n} V_i^k)} - \frac{\sum_{i=1}^{n} \ln(V_i)}{n}\right)^{-1} \quad (5)$$

$$C = \left(\frac{1}{n}\sum_{i=1}^{n} V_i^k\right)^{\frac{1}{k}} \quad (6)$$

Where: i is the measurement interval, vi (m/s) is the wind speed measured in the interval I, n is the number of nonzero wind speed data points. Eq.(5) must be solved using a iterative procedure(k=2 is a suitable initial guess).

ii. 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 conceptof least squares regression [6, 9 15]. By converting the equation (2) into logarithmic form, the following equation isobtained:

$$\ln[-\ln(1 - F(v))] = K \times \ln(v) - K \times \ln C \quad (7)$$

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

iii. Empiricalmethod

The Empirical method is the special case of the moment method, where the parameters k and c are defined by using average wind speed and standard deviation by following equations [6]:

$$K = \left(\frac{\sigma}{\bar{V}}\right)^{-1.089} \quad (8)$$

$$C = \frac{\bar{V}}{\Gamma(1+\frac{1}{K})} \quad (9)$$

$$\sigma = \left[\frac{1}{N-1}\sum_{i=1}^{n}(V_i - \bar{V})^2\right]^{1/2} \quad (10)$$

Where: $\bar{V}$ is the mean wind speed (m/s);
$\sigma$is the standard deviation of the observed data (m/s).

iv. 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:

$$E_{pf} = \frac{\overline{V^3}}{\bar{V}^3} \quad (11)$$

$$K = 1 + \frac{3.69}{(E_{pf})^2} \quad (12)$$

$$\bar{V} = C\Gamma\left(1 + \frac{1}{K}\right) \quad (13)$$

(11) Can be solved numerically or approximately by power density technique using (12)

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v. Performance of the Weibull distribution 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:

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2\right)^{\frac{1}{2}} \quad (14)$$

$$R^2 = \frac{\sum_{i=1}^{N}(y_i - z)^2 - \sum_{i=1}^{N}(y_i - x_i)^2}{\sum_{i=1}^{N}(y_i - z_i)^2} \quad (15)$$

Where: N is the number of observations, $y_i$is the actual data, xi is the predicted dataof Weibull distribution, zi is the mean wind speed.

vi. 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,

$$P(V) = \frac{1}{2} \times \rho \times A \times V^3 \quad (16)$$

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

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

$$P_D(V) = \frac{1}{2} \times \rho \times V^3 \quad (17)$$

Using expression (17) with the Weibull probability distribution the wind energy density of a site expressed as,

$$E_D = \int_0^{\infty} P_D(V) \times f(V) \times dV \quad (18)$$

Using equations (1), (4) and (17), equation (18) simplifies to,

$$E_D = \frac{\rho \times C^3}{2} \times \frac{3}{K} \times \Gamma\left(\frac{3}{K}\right) \quad (19)$$

III. RESULTS AND DISCUSSIONS

a. Results

The Weibull distribution functions, describing the wind speed frequency against the mean wind speed, was studied for the actual data in Douala. The results obtained from four methods for estimating the parameters K (shape parameter), C(scale parameter)of the Weibull wind speed distribution are summarized in the table III below.

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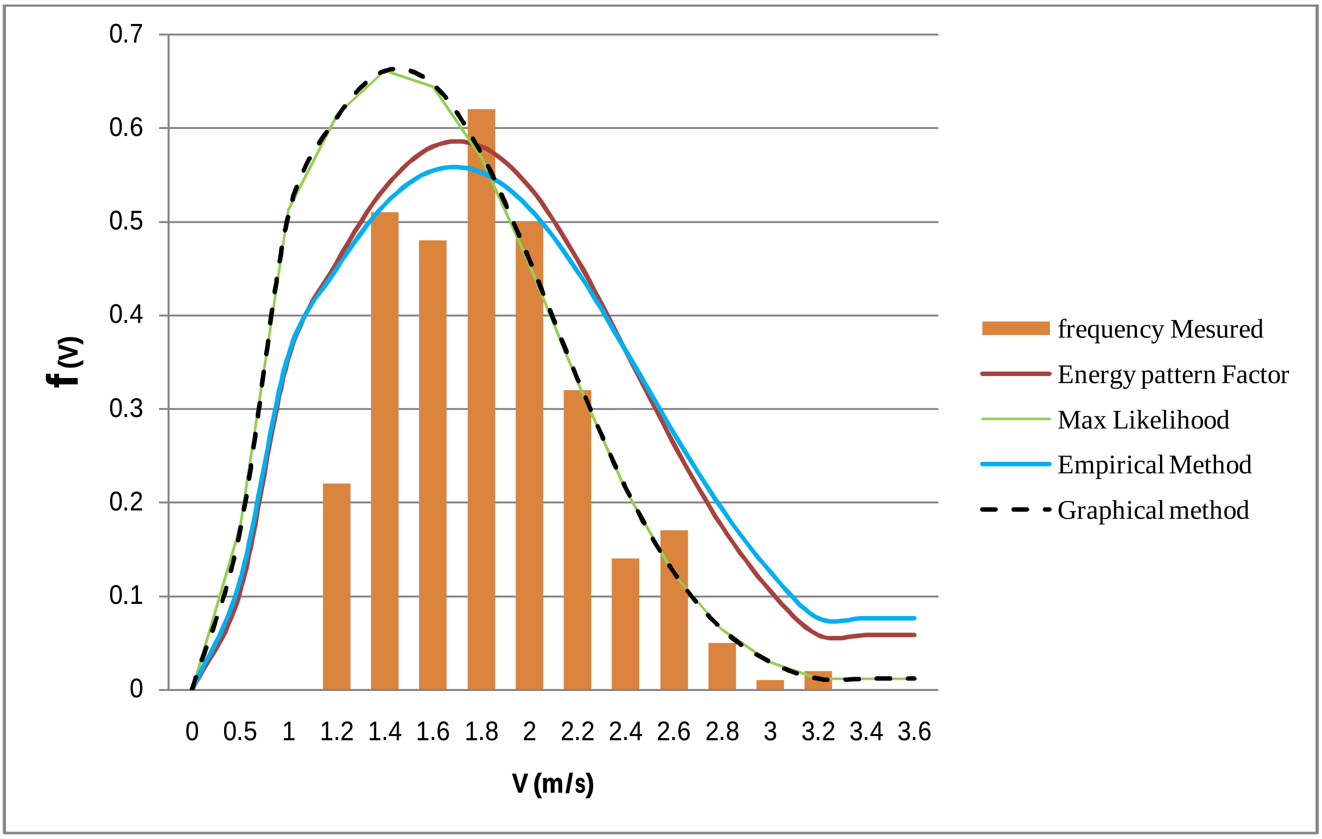
Table III: The weibull parameters and the performance of model

Numerical methods		Maximum likelihood method	Graphical method	Empirical method	Energy pattern factor method
Weibull parameters	Shape K	2.83	2.85	2.80	2.93
	Scale C	1.69	1.70	1.97	1.96
Statistical tests	R^2	0.9654	0.9651	0.9684	0.9662
	RMSE	0.0595	0.0597	0.0569	0.0587

The distribution functions and their statistical tests obtained with these parameters can be presented graphically. The frequencies measured can be also illustrated by a histogram in the same graph. Then the graph I summarize all these function and put out an idea of error between models and measured frequencies.

Graph I: Distribution function of Weibull and frequency measured



Using the Weibull distribution model obtained by the Empirical Méthod, The characteristics of wind energy potential are presented in table IV below. We tabulate the following characteristics for the wind regime prevalent in Douala.

TableIV: density of wind energy

Mean wind speed (m/s)	**Density of wind power (w/m²)**	**Monthly density of energy (kWh/m²)**	**yearly density of energy (kWh/m²)**
2.092	5.947	4.282	51.380

We tabulate the following characteristics for the wind regime prevalent in Douala.

b. Discussion

Models obtained in this study, showed the shape parameter K values ranging from 2.80 to 2.93.The Weibull scale C parameter shows an idea of the annual mean speed. The models from this analysis showed C values ranging from 1.69 to 1.97 for the mean wind speed in the Douala. The data available allowed us to obtain effective models for the four methods proposed.

The four models proposed for the Weibull wind speed distribution in the wind analysis data of the town of Douala are presented. Then these models were carried out based on the root mean square error (RMSE). Considering that the best parameters estimation must have the lowest value of RMSE and the highest value of R^2. However, the most accurate models are the empirical method followed by the energy pattern; the least precise models are the graphical and maximum likelihood method.Even though the observation from data collected in Douala, the values of RMSE and R^2 have magnitudes very close to each other for all these numerical methods.

The yearly potential of wind energy, for a height of 10 m above the ground, has been estimated around a value of 51.380kwh/m^2. This value is not relevant for an effective wind speed energy production system. But the potential is not negligible for the domestically energy, the need of the small localities far from the National electrical network.However the savonius-type wind turbine with a cut-in of 1 m/s, and having a high starting torque could be the wind turbine of choice for Douala.

IV. CONCLUSION

In this analysis, weibull models of wind speed distribution were done through four methods in the issue to evaluate the potential of wind energy in the Douala in Cameroon. Based on the data available, the models obtained are effective because all statistical tests (calculation of R^2 and RMSE) showed good performance. The best performance was empirical method with the shape parameter K = 2.8 and scale one C=1.97.

Let's observe that Douala is a locality of slow wind. The average wind speed is around 2.1 m/s. Hence Douala may not be suitable for the installation of conventional horizontal axis wind turbines whose cut-in velocity is about 4 m/s.

But may be at apposition height longer than 10m, the energy available will more interesting. This potential per unit of area cannot be negligible looking the domestically energy, the need of the small localities far from the National electrical network and also for small applications as water pumping, battery charging and lighting when the National electrical network is failing, especially in dry season.

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