

## Analysis of wind regimes for energy estimation in Bamenda, of the North West Region of Cameroon, based on the Weibull distribution

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**Abstract** - *The modelling and prediction of wind characteristics in a region is a primary requirement to the development of the corresponding wind energy system. This paper studies the wind energy potential for Bamenda in the North-West Region of Cameroon, with geographical coordinates: latitude 5.96°N, longitude 10.12°E and an elevation of 785 m. The analysis is based on data obtained from NASA surface meteorology and solar energy dataset for 11 years 1983 to 1993 through the RETScreen software tool provided by CANMET Canada. Through an analysis using the Weibull distribution function, the Weibull shape  $k$ , and scale  $c$ , parameters are determined using the least square graphical method to be 6.938 and 2.022 respectively. The mean wind speed, the variance, the standard deviation, the most probable /speed and the wind power density are also estimated characterising the wind regime of Bamenda. Comparing these results with the measured ones, it is shown that the Weibull distribution can be used with acceptable statistical accuracy for prediction of wind energy potential of Bamenda.*

**Résumé** – *La modélisation et la prévision des caractéristiques du vent dans une région est une exigence principale au développement de systèmes à énergie éolienne. Cet article consiste en l'étude du potentiel énergétique éolien de Bamenda, situé dans la région du Nord-Ouest du Cameroun, avec des coordonnées géographiques: latitude 5.96°N, longitude 10.12°E et une altitude de 785 m. L'analyse est basée sur des données radiométriques et météorologiques obtenus de la NASA sur une période de onze années de 1983 à 1993, grâce au logiciel RETScreen fourni par le CANMET Canada. Grâce à une analyse de la fonction de distribution de Weibull, avec  $k$  le coefficient de forme, et  $c$  le coefficient d'échelle, les paramètres sont déterminés en utilisant la méthode graphique des moindres carrés, et dont les valeurs sont respectivement 6.938 et 2.022. La vitesse moyenne du vent, la variance, l'écart-type, la vitesse la plus probable et la densité d'énergie éolienne sont également estimés caractérisant le régime de vent de Bamenda. En comparant ces résultats avec les résultats mesurés, il est montré que la distribution de Weibull peut être utilisée avec une précision statistique acceptable pour la prédiction de potentiel éolien de Bamenda.*

**Key Words:** Weibull distribution - Wind energy - Power density - Savonius rotor.

### 1. INTRODUCTION

The present primary energy production in Cameroon is dominated by combustible renewable and waste which constitutes 77.8 % followed by oil 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%) [1].

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According to the growth and employment strategic paper which is the reference framework for Cameroon government's action up to the year 2035, part of the long term vision of Cameroon is to be an emerging economy with an improved access to the development of energy infrastructure. For this to be possible the same paper stipulates a doubling of the national power consumption by 2020 [2].

Hence for Cameroon to attain its millenium development goals as well as being an emerging economy by 2035 there is need to develop the other sources of renewable energy. In terms of renewable energy exploitation; Cameroon as of now relies mostly on its rich hydro power potential which is the second in Africa estimated at 294 TWh/year (after the Democratic Republic of Congo with about 774 TWh/year) [3].

Eventhough hydroelectricity remains the most readily exploitable form of energy in Cameroon, it is not readily available in all parts of the country. Hydroelectricity is insufficient especially during the heart of the dry season which runs from December to march.

The wind power potential for Cameroon is at its peak during these months and can be used to supplement for the shortfalls during the dry season. Wind energy can also be generated and used in rural and remote areas which do not have access to hydroelectricity. The wind energy sector in Cameroon is not well developed and Wind energy remains marginal. With a rapid declining of the national oil reserves, there is an active campaign by the government to promote the exploitation of alternative energy resources to boost up the energy situation.

The starting point towards the implementation of a wind energy project in a region, is the thorough understanding of the prevalent characteristic wind regimes. Consequently there need to be a systematic analysis of the short term and long term wind velocity distribution from which the energy density of the site can be estimated. Such information is required for the choice and optimal sizing of the appropriate wind turbines for the region of interest.

Some attempts have been made in the past to study the wind energy potential of Cameroon but this was limited only the three northern regions of the country. The study was based on data published by the observation network of the National Meteorology Department, located in the Adamoua and Northern Cameroon regions [4]. Even though studies pointed out the feasibility of wind energy exploitation for applications such as irrigation electricity supply for small house holds it was pointed out that the study needed reinforcement by additional observations in more sites within the region of interest before general conclusions on wind energy exploitation could be made.

In the present study, the energy potential for wind regimes in Bamenda of the North West region of Cameroon will be analysed and based on the results, recommendations would be made for the harnessing and the exploitation of the available wind resource of the region. The data of wind speed for Bamenda located at latitude  $5.96^{\circ}$  N and Longitude  $10.15^{\circ}$  E, having an elevation of 785 m is analyzed. The monthly average of the wind speeds over 11-years period (1983 - 1993) is used. Wind speed values are measured at a height of 10 meters above the surface of the earth. Each monthly averaged value is evaluated as the numerical average of 3-hourly values for the given month.

These wind speed values are analyzed using the weibull two parameter distribution [5-8]. The energy content of the wind which is related to the cube of the wind speed is then calculated. The analysis is based on data obtained from NASA's satellite/analysis

data for 11 years 1983 to 1993 through the RETScreen software tool provided by CANMET Canada.

Different distribution functions have been suggested to represent wind speed data including the Gaussian distributions, exponential distributions, gamma distributions and logistics distributions [9], the Pearson function [10], Chi-Square function [11], Weibull function [5-8], Rayleigh function and Johnson function [12]. However, we note that the Rayleigh distribution is a special case of the Weibull distribution in which the shape parameter,  $k$ , is 2.

The Weibull distribution technique is widely accepted and used in the wind energy industry as the preferred method for describing wind speed variations because it stands the best fit for describing wind speed variations [13]. Consequently the analysis to follow is based on the weibull distribution.

## 2. WEIBULL DISTRIBUTION OF WIND SPEED

The Weibull probability distribution function, can be written as a three-parameter function, mathematically as [14]:

$$f(v) = \frac{k}{c-v} \times \left( \frac{v-\epsilon}{c-\epsilon} \right)^{k-1} \times \exp \left[ - \left( \frac{v-\epsilon}{c-\epsilon} \right)^k \right] \tag{1}$$

Where,  $v$  is the wind speed,  $k$  is the non-dimensional shape parameter,  $c$  is the scale parameter and  $\epsilon$  is the location parameter.

The dimensions of  $c$  and  $\epsilon$  are same as that of  $v$  (m/s). The location parameter  $\epsilon$  is the minimum wind speed and  $v \geq \epsilon$ . In this study, the minimum wind speed is 0 m/s, thus location parameter  $\epsilon$  is 0 m/s.

The weibull probability density function is given by

$$f(v) = \frac{k}{c} \times \left( \frac{v}{c} \right)^{k-1} \times \exp \left[ - \left( \frac{v}{c} \right)^k \right] \tag{2}$$

The probability density function ( $f(v)$ ) indicates the fraction of time (or probability) for which the wind is at a given velocity  $v$ .

The cumulative distribution function of the velocity  $v$  gives us the fraction of time (or probability) that the wind velocity is equal or lower than  $v$ . Thus the cumulative distribution  $F(v)$  is the integral of the probability density function. Thus,

$$F(v) = \int_0^{\infty} f(v) \times dv = 1 - \exp \left[ - \left( \frac{v}{c} \right)^k \right] \tag{3}$$

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

$$v_m = \int_0^{\infty} v \times f(v) \times dv \tag{4}$$

Upon substituting equation (2) and simplifying, we obtain:

$$v_m = c \times \int_0^{\infty} e^{-x} \times x^{1/k} \times dx \tag{5}$$

Where  $x = \left( \frac{v}{c} \right)^k$ .

Comparing equation (5) with the standard gamma function ( $\Gamma_n = \int_0^{\infty} e^{-x} \times x^{1/k} \times dx$ ), we deduce:

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

In a like manner, the mean square speed is given by

$$(v^2)_m = \int_0^{\infty} v^2 \times f(v) \times dv = c^2 \times \Gamma \left( 1 + \frac{2}{k} \right) \quad (7)$$

Now, the standard deviation of wind velocity, following the Weibull distribution is

$$\sigma_v = \left[ (v^2)_m - (v_m)^2 \right]^{1/2} = c \left[ \Gamma \left( 1 + \frac{2}{k} \right) - \Gamma^2 \left( 1 + \frac{2}{k} \right) \right]^{1/2} \quad (8)$$

The most probable value of wind velocity obtain from the weibull distribution (the one that maximizes the PDF) is given as:

$$v_{mp} = c \times \left( \frac{k-1}{k} \right)^{1/k} \quad (9)$$

## 2.1 Determination of the Weibull parameters

The Weibull distribution is characterised by two parameters; the shape parameter,  $k$ , and the scale parameter,  $c$ .  $k$  determines the uniformity of the wind. The shape parameter,  $k$ , can be interpreted directly as follows: a value of  $k < 1$  indicates that there is more concentration of energy in the wind below the average speed. A value of  $k = 1$  indicates that the wind speed is constant. A value of  $k > 1$  indicates that wind speed in the side is dominated by values above the mean speed. Knowledge of the exact value of  $k$  provides preliminary information on the wind speed regime for which wind turbine should be designed for a given region.

The scale parameter,  $c$ , determines the 'scale' or statistical dispersion of the probability distribution. If  $c$  is large, then the distribution will be more spread out; if  $c$  is small then it will be more concentrated.  $c$  gives information on the characteristic wind speed for the site for which a wind turbine should be designed.

The common methods for determining  $k$  and  $c$  are [5]:

1. Graphical method
2. Standard deviation method
3. Moment method
4. Maximum likelihood method and
5. Energy pattern factor method.

In the present analysis, the graphical method would be used which has proven to provide a better fit to measured data compared to the other methods [15].

In the graphical method, the cumulative distribution function is transformed into a linear form by taking its logarithm to obtain

$$\ln \{ -\ln [1 - F(v)] \} = k \times \ln(v) - k \times \ln c \quad (9)$$

A plot of  $\ln \{ -\ln [1 - F(v)] \}$  against  $\ln(v)$  gives a straight line with  $k$  as the slope and  $-k \times \ln c$  as the intercept along the vertical axis.

**Table 1:** Monthly wind speed average at 10 m above the surface of the earth measured from NASA Surface meteorology and Solar Energy: RETScreen Data for Bamenda (Latitude 5.96 / Longitude 10.15)

Month	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	Monthly average
Jan	2.1	1.8	2.5	2.1	2.2	2.1	2.1	2.2	2	2.2	2.1	2.1
Fev	2.1	2	2	3.1	1.9	2.1	2	2	2.4	2	2	2.2
Mar	2	1.7	1.9	2.4	3	2	1.6	2	1.7	2	2.2	2.1
Apr	2	1.8	2.5	1.5	1.4	2.1	2.5	1.5	1.7	1.8	1.8	1.9
May	2	2	1.6	2.1	1.8	2.4	1.6	1.6	1.9	1.7	1.5	1.8
Jun	2.3	2	1.8	1.7	2	1.7	1.9	1.8	2.2	1.9	2.3	2
Jul	1.6	1.5	2.2	2.1	1.8	1.7	2	2.4	1.8	1.9	1.9	1.9
Aug	2.1	1.6	1.9	2.3	1.4	1.7	2.1	2.2	1.9	2	2.4	2
Sep	2.1	2.2	1.6	1.6	1.7	1.8	1.9	1.9	1.7	2	1.7	1.8
Oct	1.6	1.4	1.7	2	1.3	1.3	1.7	1.6	1.6	1.9	1.5	1.6
Nov	1.7	1.7	2	1.9	1.9	1.7	1.7	1.6	1.7	1.6	1.5	1.7
Dec	2.1	2	1.9	2.4	1.4	2	1.8	1.8	1.5	1.4	1.6	1.8
<b>Annual average</b>	2	1.8	2	2.1	1.8	1.9	1.9	1.9	1.8	1.9	1.9	1.9

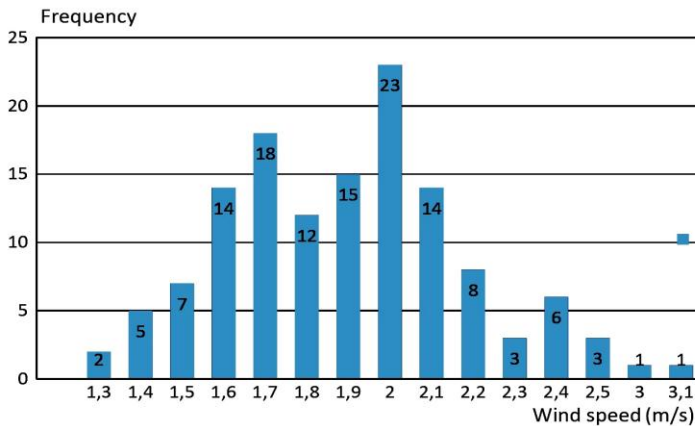


Fig. 1: Histogram of 11 years monthly average wind speeds for Bamenda

**Table 2:** Analysis of wind speed for Bamenda

Wind speed	Frequency	$f(v)$	$F(v)$	$\ln v$	$\ln[-\ln(1-F(v))]$
1.3 m/s	2 Hz	0.02	0.02	0.26	-3.9
1.4	5	0.02	0.06	0.34	-2.82
1.5	7	0.05	0.11	1.41	-2.14
1.6	14	0.11	0.22	0.47	-1.41
1.7	18	0.14	0.35	0.53	-0.83
1.8	12	0.09	0.44	0.59	-0.53
1.9	15	0.11	0.56	0.64	-0.2
2	23	0.17	0.73	0.69	0.28
2.1	14	0.11	0.84	0.74	0.6
2.2	8	0.06	0.9	0.79	0.83
2.3	3	0.02	0.92	0.83	0.93
2.4	6	0.05	0.97	0.88	1.23
2.5	3	0.02	0.99	0.92	1.52
3	1	0.01	1	1.1	1.78
3.1	1	0.01	1	1.13	-

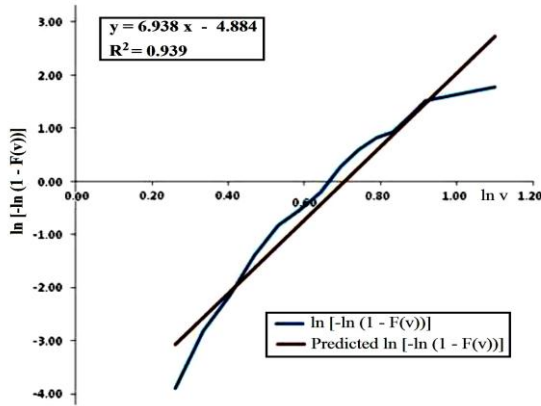


Fig. 2: Regression graph of  $\ln\{-\ln[1 - F(v)]\}$  against  $\ln(v_i)$

Fig. 2 presents a regression graph of  $\ln\{-\ln[1 - F(v)]\}$  against  $\ln(v_i)$  for the town of Bamenda based on the data presented in **Tables 1** and **2**. From the graph, the shape parameter,  $k$  is 6.938 and the scale parameter is 2.022.

The product moment correlation coefficient ‘PMCC’ which is the numerical measure of the degree of correlation between two random variables is calculated from the expression:

$$PMCC = \frac{S_{xy}}{\sqrt{S_x^2 \times S_y^2}} \tag{10}$$

Where,

$$S_{xy} = \frac{\sum_{i=1}^n x_i y_i}{n} - \bar{x}\bar{y} \quad , \quad S_x^2 = \frac{\sum_{i=1}^n x_i^2}{n} - (\bar{x})^2 \quad , \quad S_y^2 = \frac{\sum_{i=1}^n y_i^2}{n} - (\bar{y})^2$$

For this study, the ‘PMCC’ is 0.969. This value is very small and close to 1 implying that there is a high or good linear relationship between the variables. The coefficient of determination (COD or  $R^2$ ) which is a measure of the explanatory power of a calculated regression model is indicated on the graph as 0.939.

From the weibull distribution, the mean wind speed, the variance, the standard deviation and the most probable wind speed can respectively be calculated from the equations (6), (7), (8) and (9). For this study these quantities are respectively 1.891, 0.103, 0.320 and 1.997.

The graphs of the PDF and the cumulative distribution function of the Weibull distribution for Bamenda are shown below in Fig. 3 and 4.

### 2.2 Determination of wind energy density and energy available in the wind spectra

The energy available in a wind regime is determining factor to setting up a wind energy project. 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 wind energy density ( $E_D$ ) is the energy available in the regime for a unit rotor area and time.

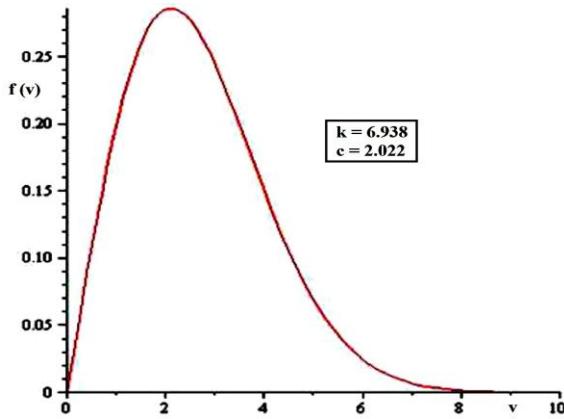


Fig. 3: A graph of Weibull  $f(v)$  against  $v$  for Bamenda

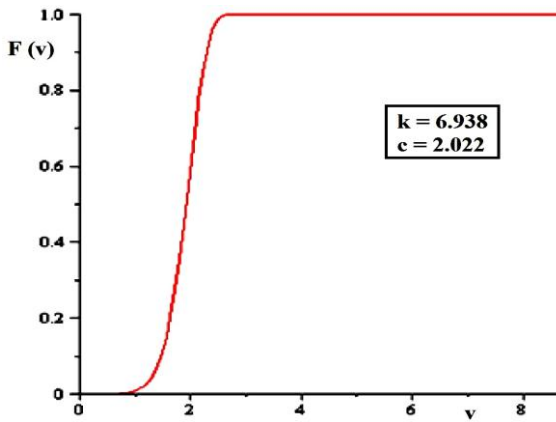


Fig. 4: A graph of Weibull  $F(v)$  against  $v$  for Bamenda

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,

$$P_D(v) = \frac{1}{2} \times \rho \times v^3 \tag{11}$$

Using this expression together with the Weibull probability distribution the wind energy density of a site expressed as,

$$E_D = \int_0^\infty P_D(v) \times f(v) \times dv \tag{12}$$

Using equations (2), (5) and (11), equation (12) simplifies to,

$$E_D = \frac{\rho \times c^3}{2} \times \frac{3}{k} \times \Gamma\left(\frac{3}{k}\right) \tag{13}$$

The energy density can then be used to calculate an estimated value of the energy available in the wind spectra ( $E_S$ ) for some determined time interval  $T$ . Hence;

$$E_T = E_D \times T = \frac{\rho \times c^3}{2} \times \frac{3T}{k} \times \Gamma\left(\frac{3}{k}\right) \quad (14)$$

Other important factors necessary for planning a wind energy project include: the most frequent wind velocity ( $V_{Fmax}$ ) and the velocity contributing the maximum energy ( $V_{Emax}$ ) to the wind regime. The peak of the probability density curve represents ( $V_{Fmax}$ ). Due to the cubic velocity-power relationship of wind, the velocity contributing the maximum energy is usually higher than the most frequent wind velocity [5].

Wind turbines are generally designed to operate at their maximum efficiency point corresponding to a wind velocity usually called the designed wind speed ( $V_{Emax}$ ); which is higher than the most frequent wind speed. The designed wind speed ( $V_{Emax}$ ) most at times is chosen to correspond to the wind speed carrying the maximum amount energy.

Hence the designer would a priori like to identify ( $V_{Emax}$ ) for a particular site in order to produce wind turbines that would function optimally for the site. The the most frequent wind speed ( $V_{Fmax}$ ) is obtained by requiring  $df(v) / dv = 0$ . From equation (2), this condition leads to:

$$V_{Fmax} = c \times \left(\frac{k-1}{k}\right)^{1/k} \quad (15)$$

The wind energy associated to any particular wind speed is given by:

$$E_v = P_D \times f(v) \quad (16)$$

Hence from equations (2) and (11), we get:

$$E_v = \frac{1}{2} \times \rho \times v^3 \times \frac{k}{c} \times \left(\frac{v}{c}\right)^{k-1} \times \exp\left[-\left(\frac{v}{c}\right)^k\right] \quad (17)$$

The velocity contributing the maximum energy ( $V_{Emax}$ ) is obtained by requiring  $dE_v / dv = 0$ . From equation (17), this condition leads to:

$$V_{Emax} = c \times \left(\frac{k+2}{k}\right)^{1/k} \quad (18)$$

If we reason in terms of the range of wind speeds for which a wind turbine functions; it will vary between the cut in wind velocity  $v_{in}$ , the rated velocity  $v_R$  and the cut out wind velocity  $v_{out}$ . The wind turbine only starts rotating for wind speeds greater than  $v_{in}$  attains maximum efficiency at  $v_R$  while between  $v_R$  and  $v_{out}$  it is producing constant power corresponding to the rated velocity of the wind turbine. Above the cut out wind velocity  $v_{out}$  the wind turbine is shut down to avoid being destroyed by the strong wind which at this time would be producing a very high thrust force.



Hence the effective power that can be captured by the wind turbine is given by:

$$E_{\text{eff}} = T \times \int_{v_{\text{in}}}^{v_{\text{R}}} P_{\text{D}}(v) \times f(v) \times dv + T \times P_{\text{r}} \int_{v_{\text{R}}}^{v_{\text{out}}} f(v) \times dv \quad (19)$$

$$E_{\text{eff}} = \frac{T \times \rho \times k}{2c^k} \int_{v_{\text{in}}}^{v_{\text{R}}} v^{k+2} \times \exp\left[-\left(\frac{v}{c}\right)^k\right] \times dv + T \times P_{\text{r}} \int_{v_{\text{R}}}^{v_{\text{out}}} f(v) \times dv \quad (20)$$

This, upon integrating and making use of the fact that  $\int f(v) \times dv = F(v)$  can be expressed as,

$$E_{\text{eff}} = \frac{T \times \rho \times k}{2c^k} \int_{v_{\text{in}}}^{v_{\text{R}}} v^{k+2} \times \exp\left[-\left(\frac{v}{c}\right)^k\right] \times dv + \frac{1}{2} \rho \times v_{\text{R}}^3 \times T \left( \exp\left[-\left(\frac{v_{\text{R}}}{c}\right)^k\right] - \exp\left[-\left(\frac{v_{\text{out}}}{c}\right)^k\right] \right) \quad (21)$$

Details of the calculations in this section are presented in [5].

### 3. RESULTS AND DISCUSSION

Based on the calculations section 3, and on the values of the shape and scale parameters; with respective values,  $k = 6.938$  and  $c = 2.022$ . We tabulate the following characteristics for the wind regime prevalent in Bamenda.

$$E_{\text{D}} = 1.494 \text{ W/m}^2$$

$$E_{\text{T}} = 1.076 \text{ kWh/m}^2/\text{month} \quad , \quad E_{\text{T}} = 13.089 \text{ kWh/m}^2/\text{year}$$

$$V_{\text{Fmax}} = 1.977 \text{ m/s} \quad , \quad V_{\text{Emax}} = 2.097 \text{ m/s}$$

$$E_{\text{AG}} = 3.225 \text{ kWh/m}^2/\text{month} \quad , \quad E_{\text{AG}} = 39.238 \text{ kWh/m}^2/\text{month}$$

The energy available for the wind turbine ( $E_{\text{AG}}$ ) is calculated based on a cut-in speed of 1 m/s and a cut-out speed of 12 m/s. Eventhough  $V_{\text{Fmax}}$  and  $V_{\text{Emax}}$  are very close to 2 m/s we observe from the cumulative frequency that such an average wind speed persists for about 80 % of the year.

Hence Bamenda may not be suitable for the installation of conventional horizontal axis wind turbines whose cut-in velocity is about 4 m/s. How ever the savonius-type wind turbine with a cut-in of 1 m/s [16], and having a high starting torque could be the wind turbine of choice for Bamenda.

### 4. CONCLUSION

This paper has analysed the wind potential of Bamenda in the North-West region of Cameroon for energy exploitation based on the Weibull distribution. Data for the analysis was obtained from NASA's satellite/analysis data for 11 years 1983 to 1993 through the RETScreen software tool provided by CANMET Canada.

The weibull shape and scale parameters were obtained followed by values of: the most frequent wind velocity ( $V_{Fmax}$ ) and the velocity contributing the maximum energy ( $V_{Emax}$ ) to the wind regime. These last two speeds were of the order of 2 m/s showing that Bamenda is not suitable for commercial wind turbine installation.

However such wind speeds are prevalent for over 80 % of the year showing that the slow running Savonius rotor could be a suitable choice. A number of such units can power rural households which are not connected to the grid, and can serve also for water pumping, battery charging and other medium power stand-alone applications.

## NOMENCLATURE

c : Weibull scale factor	k : Weibull shape factor
T : Time period in hours	$P_D$ : Power density, W/m <sup>2</sup>
$\rho$ : Air density, kg/m <sup>3</sup>	$V_{Fmax}$ : Most frequent wind speed
$E_D$ : Wind energy density W/m <sup>2</sup>	$E_{AG}$ : Energy available for the wind turbine
$V_{Emax}$ : Velocity containing maximum energy in a wind regime	$E_S$ : Total energy available in the wind spectra during the period, kWh/m <sup>2</sup>

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