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Original Research Article

STATISTICAL ESTIMATION OF MEAN WIND ENERGY AVAILABLE IN WESTERN REGION OF CAMEROON: CASE OF THE BAFOUSSAM'S CITY.

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Abstract: Wind plays a crucial role in many physical applications such as wind energy explorations, pollutants transport and diffusion. Wind is considered to be highly variable from both of temporal and geographical point of views. This is why this paper deals with the investigation of wind potential energy in one of the most important city of Cameroon, the Bafoussam's city of the western region, with the data obtained both from the Bafoussam airport and the NASA meteorological services. By the using of the maximum entropy principle (MEP) we have derived a family of pre-exponential distributions in order to describe wind speed probability distributions. The statistical performances of the developed distributions are compared with those of the conventional Weibull distributions.

As a result it has been found that Bafoussam is the low potential site for installing wind turbine. The average annually wind speed within the chosen time interval being 1.6 m/s, which can be classified as class 1, according to the international system wind classification. Moreover, the result shows that the night time is the windy time, while 22h30 is the windiest moment.

Keywords: Pulse Wind potential energy; annually wind speed; Maximum entropy principle; Lagrangian parameters.

Introduction: Wind is a particular source of free renewable energy which is vigorously exploited by many countries of the world in general and more precisely in Cameroon. This energy is a cheap, clean and non-polluting, and may finally be used to replace the expensive fossil fuels. Particularly, Cameroon is one of the African countries with huge renewable energy potentials and especially in the rural areas where renewable energy resources such as solar, hydropower, wind and biomass could be used to provide basic modern energy services for rural development and poverty alleviation. In spite of these enormous potentials, the constant rise in energy costs, the problem of persistent (power) blackout and most importantly increasing awareness of climate change have motivated us

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to study the wind energy as an alternative energy used in Cameroon[1].

More generally, the wind energy is characterized by a high variability both in space and time. This is why it is very important to describe the variation of wind speeds for optimizing the design of the systems, and in order to reduce energy-generating costs [2, 3, 4]. More recently, numerous studies have been carried out to assess the wind speed characteristics and associated wind energy potentials in different parts of the world, which involves trying to determine sites with the best wind energy potential [5, 6, 7]. Therefore a national wind resource assessment and mapping should indicate whether or not a country has the potential to utilize the wind energy. This work has essentially been focused on collecting data of speed and direction of wind. Thus, the paper is organized as follows: In Sec.2, the methodology of our investigations namely, the statistical analysis of wind speed variation, the statistical analysis of maximum entropy principle is presented. Next in Sec.3, constituting one of the main parts of the paper, we present the obtained results and provide discussions. Finally in Sec.4, concluding remarks are devoted.

Methodology

Statistical analysis of wind speed variation: Weibull distribution function: In statistical analysis of wind speed variation, the Weibull two-parameter distribution function has been widely applied by many researchers [4] to characterize wind speeds for wind energy resources. This Weibull distribution admits the probability density function which can be expressed as [8, 9]

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left(-\left(\frac{v}{c}\right)^{k}\right), \qquad (1)$$

where v is the wind speed expressed in m/s, while the parameters k and c (usually used to express the Weibull probability density function) are the Weibull shape and scale factors, respectively. The scale factor has the dimension of wind speed and it should be greater than zero. The shape factor k has no dimension and it ranges generally from 1.5 to 3 for most wind conditions [15].

Statistical Analysis of Maximum entropy principle: Let us remember the Carta et al. [10] principles, which suggest the probability density function f(v) to be obtained by minimizing the Shannon's entropy under the following restrictions:

- The sum of all of the probabilities within the definition interval must be equal to one, that is

$$\int_0^{\max(v)} f(v)d(v) = 1, \qquad (2)$$

- The M-low statistical orders m_i' (i=1,2,...,M) with respect to the theoretical distribution must be equal to the M-low statistical orders with respect to the empirical distribution, meaning mathematically to

$$\int_0^{\max(v)} v f(v) d(v) = m_i', \qquad (3)$$

where the M-low statistical orders m_i' are obtained empirically as [3]:

$$m_i' = \frac{1}{N}\sum_{i=1}^{N} v^i, \qquad (4)$$

The expression of a general solution of equation 1 and 2 can be given as [11]

$$f(v) = \exp\left(\sum_{j=1}^{M} \alpha_j v^i\right), \qquad (5)$$

where α_j are Lagrangian multipliers, which can be obtained by the standard Newton method and M is the number of the used low order moments.

Wind power Analysis: In many applications such as the wind energy field, the wind speed distribution, generally considered as an adequate indicator of the wind energy resource is used to estimate the wind energy. For a surface A, the wind power density E, expressed in Watt per square of the meter W/m^2, takes into account of the frequency distribution of the wind speed, the dependency of wind power on air density, and the cube of the wind speed. This wind power density is given by [12, 13]

$$E = \frac{P}{A} = \int_0^{\infty} \frac{1}{2}\, \rho\, v^3 f(v) d(v), \qquad (6)$$

in which P is the wind power, and ρ the mean air density $(\rho = 1.225\ kg/m^3$ at average atmospheric pressure (that is at sea level) and at $15^o\ C$).

Results and discussion

Preliminaries: For the purposes of our study, the wind speed data for Bafoussam, saved by the meteorological station airport for the period going to 2007 to 2013, giving the frequency distribution of the wind speed (as given in Table 1), and by the meteorological station of NASA for the period going to July 1983 to June 1993 and from 2005 to 2014, which give the yearly and seasonal mean wind speed (as given in Table 2), were used. The analyses were performed using Microsoft Excel and self developed Matlab program. The Weibull distribution parameters in terms of k and c, the mean power density and the mean wind speed were determined for the daily, monthly, seasonal and yearly variations.

Table 1: Yearly cumulative frequency of the wind blows according to wind speeds collected in an interval of three hours

Wind speed, expressed in (m/s)	Frequency distribution for the years:							Total within 7-years
	2007	2008	2009	2010	2011	2012	2013	
0-1	197	191	225	347	398	316	371	2045
1-2	203	195	169	118	145	107	107	1044
2-3	345	331	379	370	365	396	469	2655
3-4	471	487	437	463	472	556	531	3417
4-5	279	364	402	290	209	257	289	2090
5-6	109	160	127	49	47	39	45	576
6-7	45	80	65	22	20	9	12	253
7-8	12	22	21	12	14	0	1	91
8-9	0	0	0	3	0	0	0	3
Total per year	1661	1830	1825	1674	1670	1770	1825	12174

- According to Table 2 (first column), it is obvious that all the annually mean wind speed calculated are lower than $2.0m/s$. The maximum value being $1.8m/s$ and obtained in 2011 and 2012, while the minimum value is $1.5m/s$ obtained in years: 2006, 2007, 2013 and 2014, meaning that Bafoussam is a low potential site to generate electricity via wind energy system.

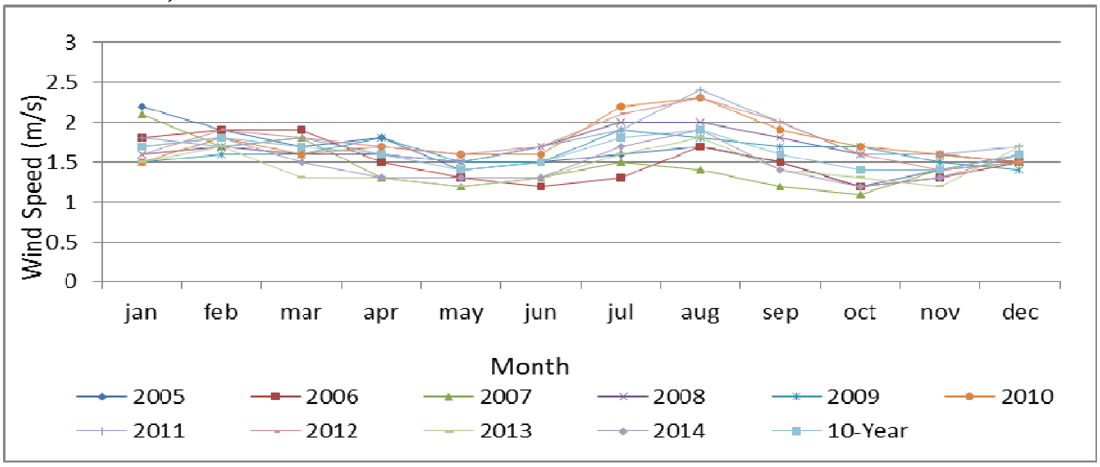

Figure1: Monthly mean wind speed variations between 2005 and 2014, and the whole study period

Table 2: Mean wind speed variations between 2005 and 2014, and the whole study period

Years	Mean wind speed expressed in (m/s) and obtained:		
	Yearly	Cold Season	Warm Season
2005	1.6	1.0	1.8
2006	1.5	1.4	1.7
2007	1.5	1.3	1.7
2008	1.7	1.7	1.6
2009	1.6	1.7	1.5
2010	1.7	1.9	1.6
2011	1.8	1.8	1.7
2012	1.8	1.9	1.6
2013	1.5	1.4	1.5
2014	1.5	1.4	1.6
Mean wind speed in 10-Years	1.6	1.6	1.6

- Next, Fig1 is plotted to analyze the monthly mean wind speeds variation for each year between the interval 2007 to 2013 as well as the total mean wind speed within ten years interval. We notice that the monthly mean wind speed for each year is greater than $1.0m/s$. For the overall ten years, the maximum value of the mean wind speed is $2.4m/s$ and it occurs in August, while the minimum value is $1.1m/s$ obtained in October. From Table 2 (second and third column) we notice that there is a minor change of mean wind speed during the cold and warm seasons.
- In order to analyze the daily repartition of the mean with speed, Fig. 2 illustrating the diurnal wind speed is plotted from July 1983 to June 1993, according to which it results that the yearly overall and the two seasons (cold and warm) defined above present the similar shape. It can also be seen that the highest wind speed occurred during the night time. Figure 3 presents the diurnal wind speed variations for the individual months from July 1983 to June 1993 obtained from the NASA station, from where we notice that particularly in August, the wind speeds are greater than 1.3m/s and the maximum wind speed reaches 3.1m/s in the nighttime. However, the calmest month occurs in October, and in that month, the wind speed is lower than 2.5m/s. The salient features of the statistical calculation can be given as follows:

Wind direction analysis: Before installation of a wind turbine, it is important to know its proper orientation beforehand so that conversion of available wind speeds into mechanical energy is optimized. Similarly, the choice of a target installation site of a wind turbine is guided by acceptable criterion that yields maximum power, which can be performed by analyzing the wind speed distributions in the various directions and the most dominant wind direction [16]. Thus, Fig.4 shows the wind direction frequency distributions for the individual and overall seven years from the NASA station, from where it is obvious that for all the years, the wind directions have a similar pattern. The prevailing wind directions are north sector and in these sector 35% of the wind blew from north. West, East and South-East sector are another main sector, but its frequencies are only 20% and 15%, respectively. The investigated wind direction frequency distributions for the cold and warm seasons are shown in Fig.5 (left and right), respectively. For these two seasons, the dominant wind direction is similar to the yearly distribution. The monthly wind direction variations for each month in the cold season, from April to October, are shown in

Fig.6 (a-g), respectively. The prevailing wind directions are north sector except for July and August, for which the dominant wind direction is the West.

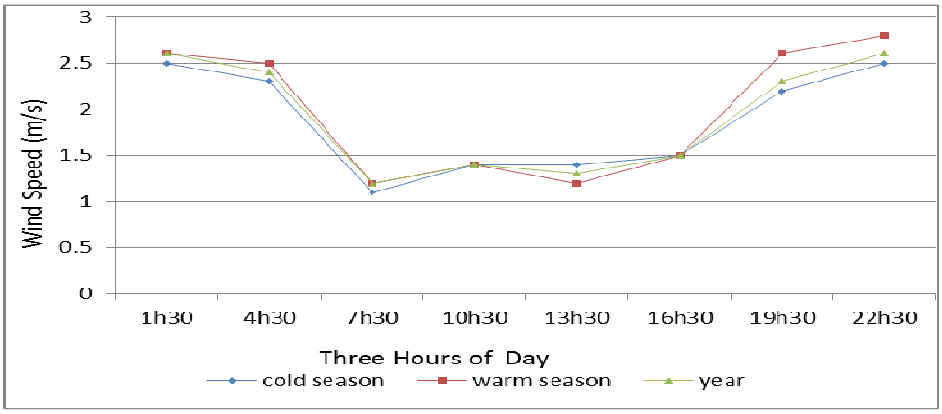

Figure 2: Daily mean wind speed variations for Cold Season (May-October), Warm Season (November-March) and whole year based on 10-year data (July1983-June1993).

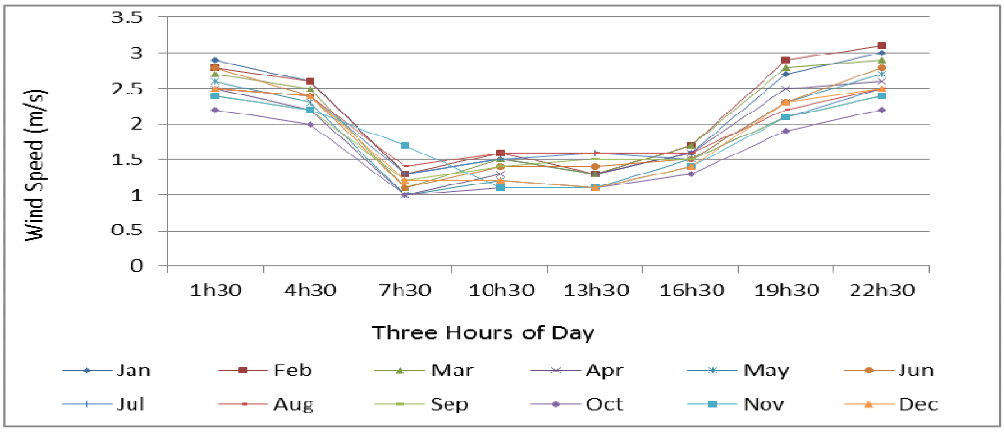

Figure 3: Daily mean wind speed variations for individual month based on 10-year data (July1983-June1993).

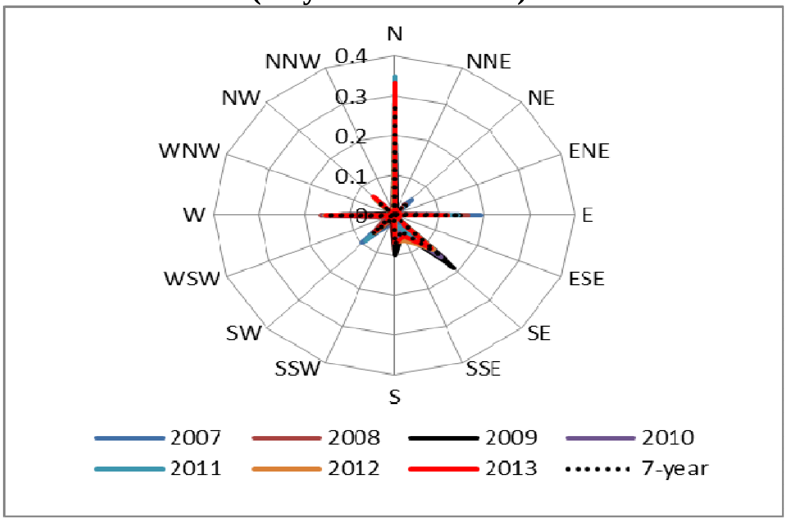

Figure 4: Wind direction frequency distributions between 2005 and 2014, and the whole study period

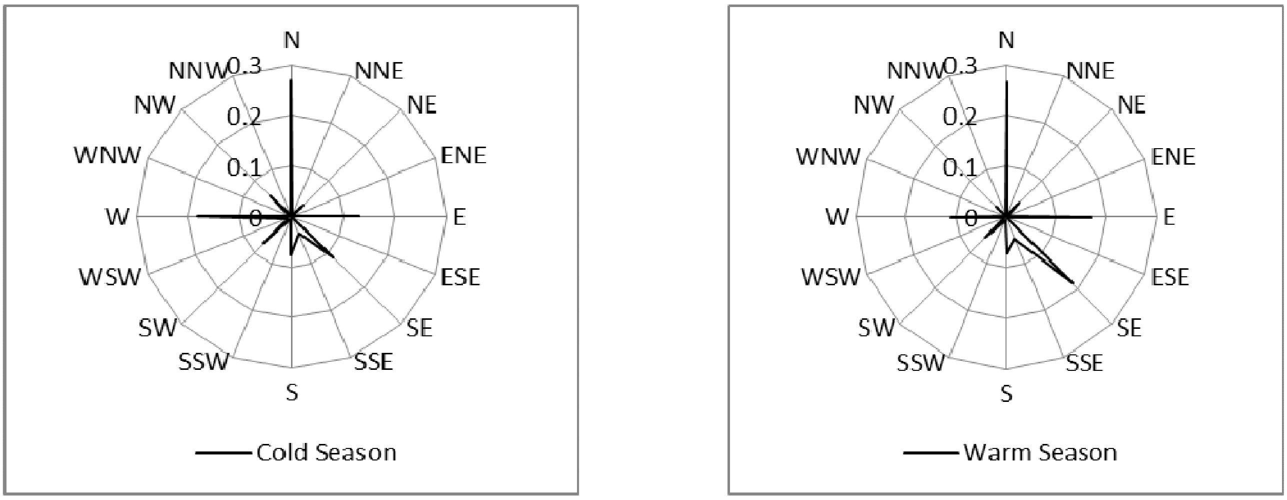

Figure 5: Wind direction frequency distributions for Cold Season (April-October), Warm Season (November-March) based on 7-year data (2007-2013), (left: Cold Season; right: Warm Season).

Wind speed frequency distribution analysis

Computed MEP based wind speed distribution and data: The Lagrangian parameters obtained through the Newton-Raphson iterative method for the monthly distributions and Weibull parameters are presented in Table 4, from where the distributions for each month is plotted as shown in Fig.7. It can be seen that particularly for the cold season, Bafoussam region doesn't have a relatively high frequency of calm period. It is also important to mention from our analysis that, the MEP model is more accurate than the empirical Weibull distribution. To study the different mentioned models, we have calculated the following statistical parameters: $\mathrm{COD} = \mathrm{R}^2$, with [13, 14].

$$\mathrm{COD} = \mathrm{R}^2 = [\textstyle\sum_{i=1}^{n}(y_i - y_m)^2 - \sum_{i=1}^{n}(y_{ic} - y_i)^2]/[\sum_{i=1}^{n}(y_i - y_m)^2], \qquad (7)$$

$$\chi^2 = [\textstyle\sum_{i=1}^{n}(y_i - y_{ic})^2]/y_i\,, \qquad (8)$$

$$\mathrm{RMSE} = \left[\frac{1}{n}\sum_{i=1}^{n}(y_i - y_{ic})^2\right]^{1/2}, \qquad (9)$$

where R^2 is the correlation coefficient, χ^2 is the Chi-Square coefficient and RMSE is the root mean square error. Table 5 shows these statistical parameters for all the monthly MEP based wind speed distributions. It can result that COD varies from 0.9989 to 0.9995 each months. Otherwise, the Lagrangian parameters for Cold and Warm Seasons are shown in Table 6. The corresponding Lagrangian multipliers for whole day distributions are also listed in this table and the comparison between the MEP based distribution and the measured data are illustrated in Fig.8 (a) and (b). The parameters of the statistical analysis for the two seasons are illustrated in Table 6. Figure 9 shows the wind speed distributions for the whole day based on the correspondingly measured data.

Wind energy potential analysis: The wind data collected after three hours interval, and in seven-years (from 2007 to 2013) from the meteorological station of airport Bafoussam table are indicating the occurrence frequencies f(v) of the wind speeds, the wind characteristics are presented in Table 7. This table shows monthly variations for the mean power density that is calculated using MEP wind speed distribution function. As seen from this table, the highest mean power density, 29.2323 W/m^2 occurs in February while the lowest is in September with the value of 14.9229 W/m^2.

Table 3: The computed Lagrangian multipliers, and Weibull parameters for individual months based on 7-year data (2007-2013) in Bafoussam region, Cameroon.

Year	Weibull parameters		Lagrange multiplieurs for MEP distribution			
	k	c	α_0	α_1	α_2	α_3
January	1.4941	2.6930	1.7203	0.4424	-0.3081	0.0491
February	1.6580	3.1154	2.1474	-0.1817	-0.0551	0.0184
March	1.6256	3.0314	2.0890	-0.1557	-0.0594	0.0191
April	1.7555	2.9011	2.1669	-0.1490	-0.1398	0.0361
May	1.7316	2.7799	2.0364	0.1195	-0.2811	0.0565
June	1.6745	2.7205	1.9850	0.0728	-0.2347	0.0495
July	1.7001	2.7923	2.0747	-0.0983	-0.1516	0.0381
August	1.7273	2.6544	1.9947	0.1633	-0.3325	0.0682
September	1.6309	2.5037	1.7457	0.7897	-0.6604	0.1151
October	1.7041	2.6035	1.9822	0.0861	-0.2884	0.0631
November	1.6466	2.7208	2.0253	-0.1476	-0.1087	0.0322
December	1.4896	2.6043	1.7319	0.3171	-0.2604	0.0456

In addition, seasonal variation of the mean power density is shown in Table 8 from where it is obvious that the value of the mean power density for the cold season is 18.1 W/m^2, while this value is 23.6 W/m^2 in Warm Season. The mean power density of whole day being calculated as 20.4 W/m^2

Table 4: The statistical analysis parameters for monthly wind speed distributions.

Year	Weibull distribution			MEP distribution		
	COD	RSME	χ^2	COD	RSME	χ^2
January	0.9965	0.0126	0.0678	0.9991	0.0070	0.0225
February	0.9982	0.0106	0.0417	0.9992	0.0084	0.0209
March	0.9984	0.0094	0.0326	0.9994	0.0068	0.0146
April	0.9971	0.0133	0.0626	0.9989	0.0094	0.0245
May	0.9956	0.0143	0.0899	0.9991	0.0077	0.0230
June	0.9970	0.0127	0.0570	0.9995	0.0062	0.0094
July	0.9974	0.0119	0.0485	0.9994	0.0068	0.0119
August	0.9969	0.0115	0.0553	0.9994	0.0059	0.0121
September	0.9944	0.0149	0.0919	0.9995	0.0053	0.0093
October	0.9964	0.0122	0.0619	0.9992	0.0065	0.0156
November	0.9961	0.0145	0.0827	0.9981	0.0118	0.0469
December	0.9955	0.0137	0.0870	0.9984	0.0095	0.0306

Table 5: The computed Lagrangian multipliers and Weibull parameters for whole day, Cold Season (April-October) and Warm Season (November-March) based on 7-year data (2007-2013).

	Weibull parameters		Lagrange multiplieurs for MEP distribution			
	k	c	α_0	α_1	α_2	α_3
Whole day	1.6342	2.7558	1.9836	0.0183	-0.1589	0.0368
Cold Season	1.6980	2.7013	1.9970	0.0908	-0.2630	0.0552
Warm Season	1.5686	2.8306	1.9323	0.0191	-0.1299	0.0284

Table 6: The statistical analysis parameters for seasonal (Cold Season: April-October; Warm Season: November-March) wind speed distribution in Bafoussam region, Cameroon.

		Whole day	Cold Season	Warm Season
MEP distribution	COD	0.9990	0.9993	0.999
	RSME	0.0023	0.0026	0.0038
	χ^2	0.0219	0.0150	0.0264
Weibull distribution	COD	0.9978	0.9975	0.9981
	RSME	0.0035	0.0049	0.0052
	χ^2	0.0616	0.0655	0.0553

Table 7: Monthly wind power density (expressed in W/m^2) based on 7-years data (2007-2013).

Year	Wind power density	
	Weibull distribution	MEP distribution
January	23.9336	21.5816
February	31.1079	29.2323
March	29.5496	27.6807
April	23.170	21.7099
May	20.7777	19.2411
June	20.4447	18.8958
July	21.6156	20.1464
August	18.1529	16.7612
September	b16.595	14.922
October	17.4633	16.1344
November	20.9771	19.5322
December	21.7861	19.7083

Table 8: Monthly wind power density (expressed in W/m^2) based on 7-years data (2007-2013).

	Wind power density	
	Weibull distribution	MEP distribution
Cold Season	19.6058	18.1263
Warm Season	25.5167	23.5801
Year	22.0546	20.4285

Concluding remarks: In present study, assessment of the wind characteristics and power potential in the western region of Cameroon, based on a measured data source over 20-year period (July 1983 to June 1993 and 2005 to 2014) are estimated. Annual, Seasonal, monthly and daily wind speed and direction variations are investigated. From the wind direction analysis, it has been found that the prevailing wind direction is the north sector. The diurnal trend shows that night time is windier than day time in this region. By using the maximum entropy principle (MEP) and the Weibull distribution, we have computed the wind speed distributions, from where it is found that the MEP is more accurate that the Weibull distribution for our obtained data. It is also important to mention that the higher power is obtained in February and the lowest in September.

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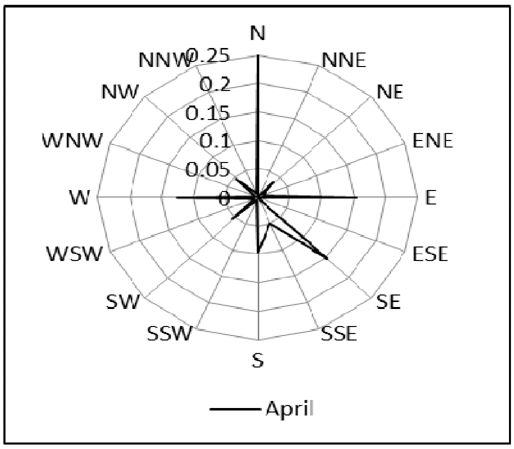
(a)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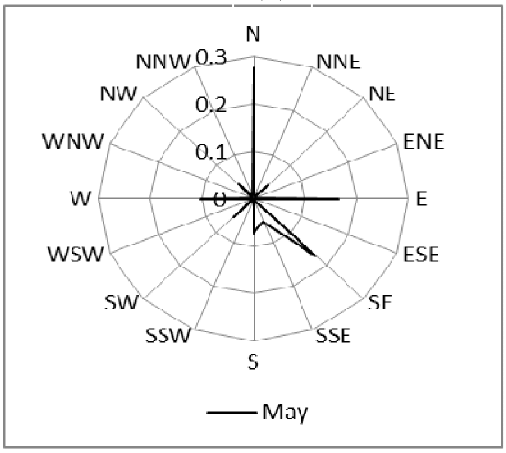
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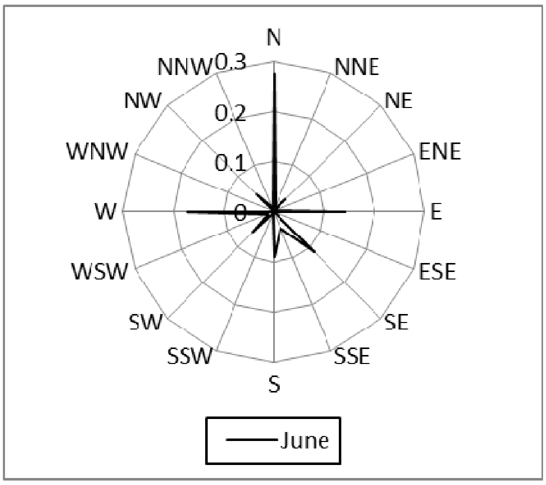
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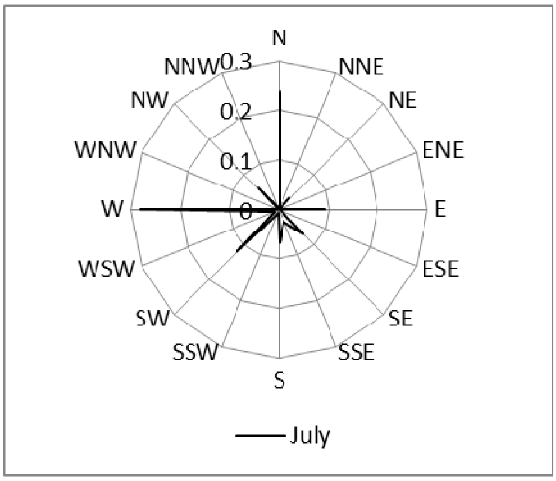
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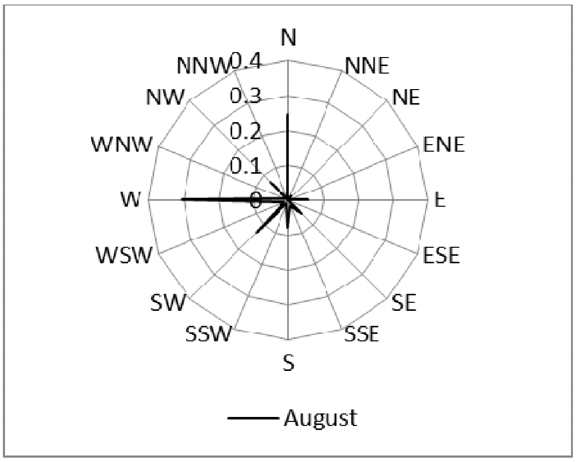
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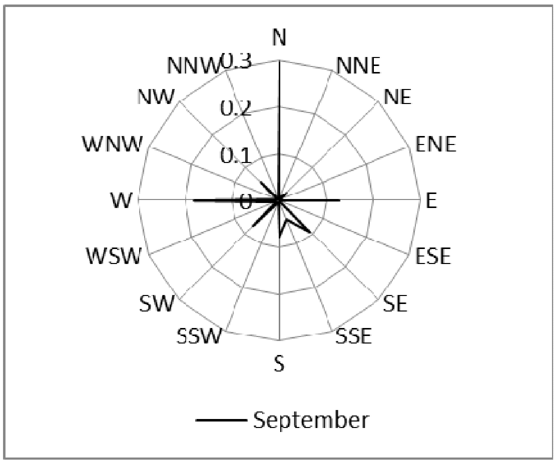
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(g)

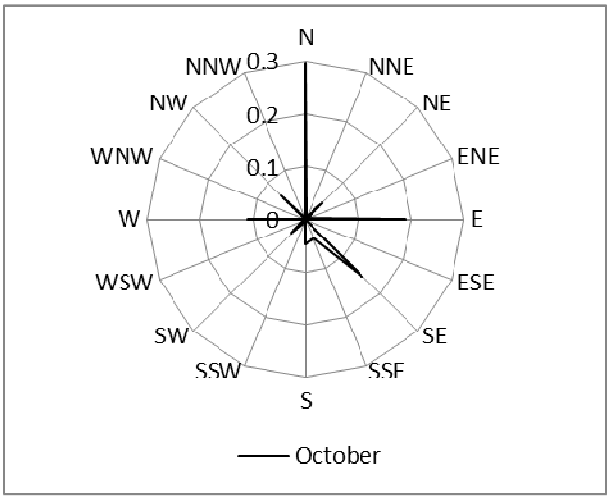
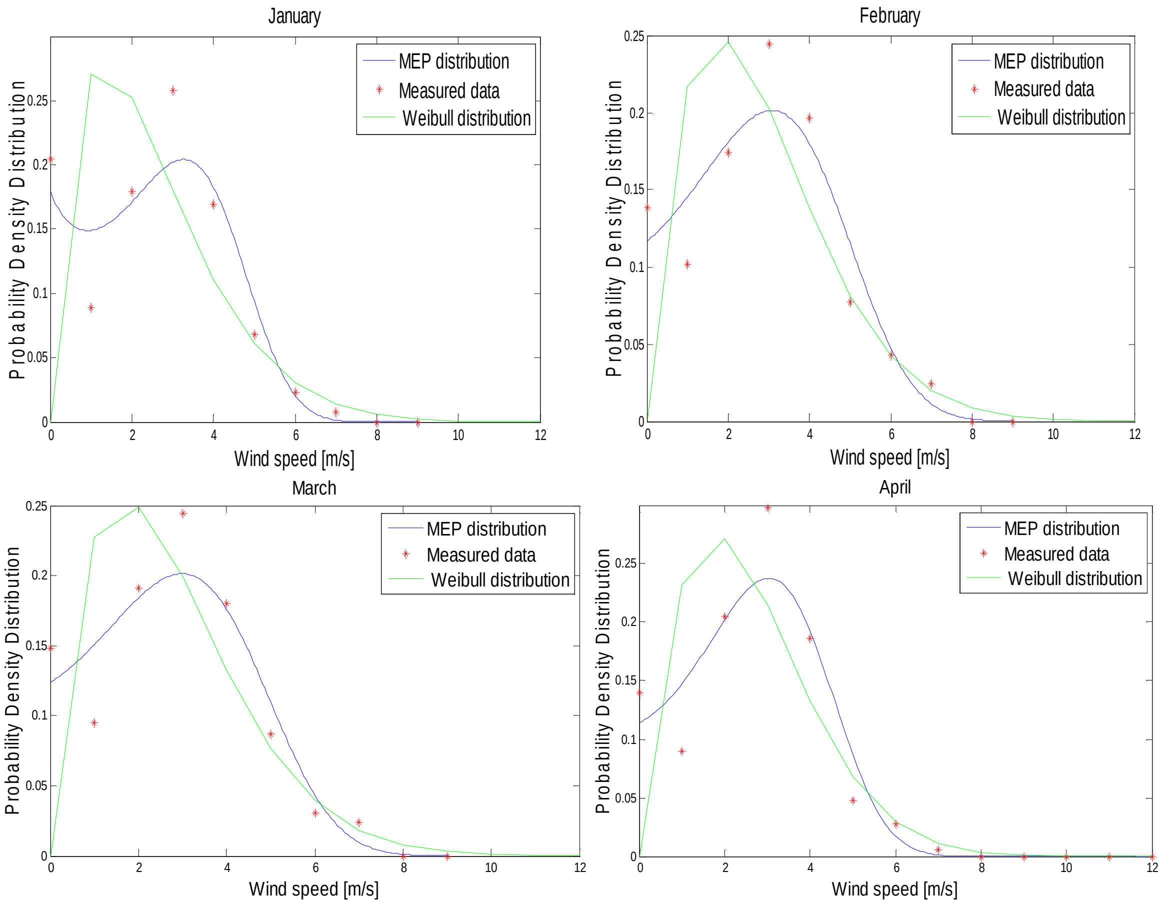
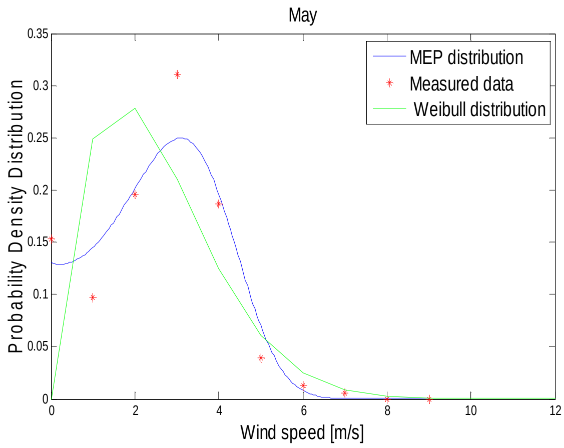
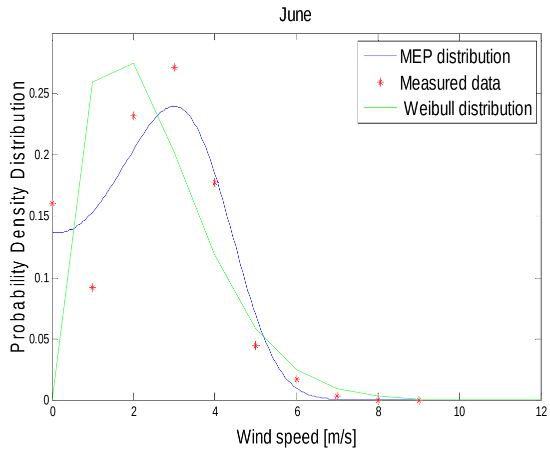
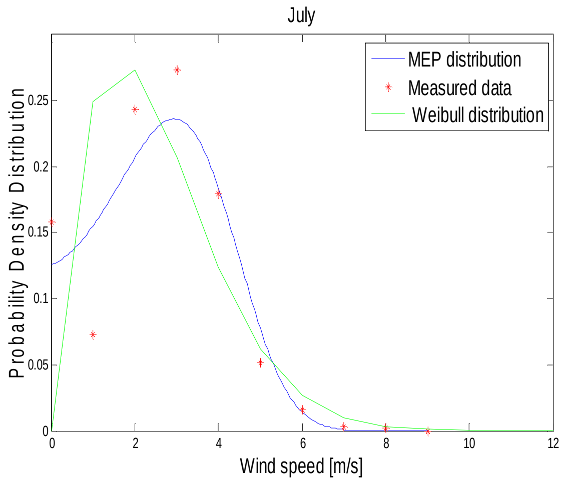


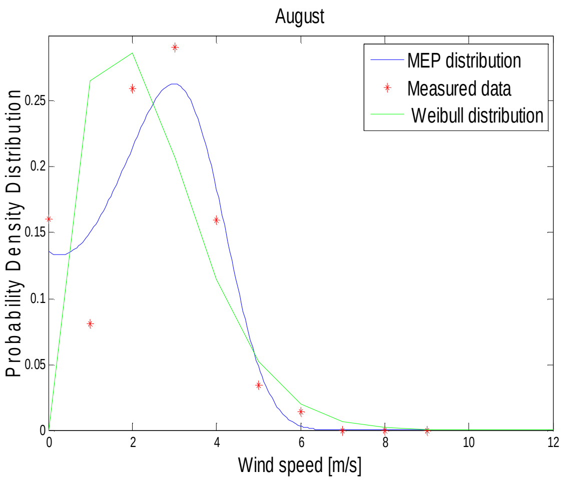
Figure 6: Wind direction frequency distributions for individual months in Cold Season (April-October) based on 7-year data (2007-2013), in Bafoussam region, Cameroon ((a) April; (b) May; (c) June; (d) July; (e) August; (f) September; (g) October).

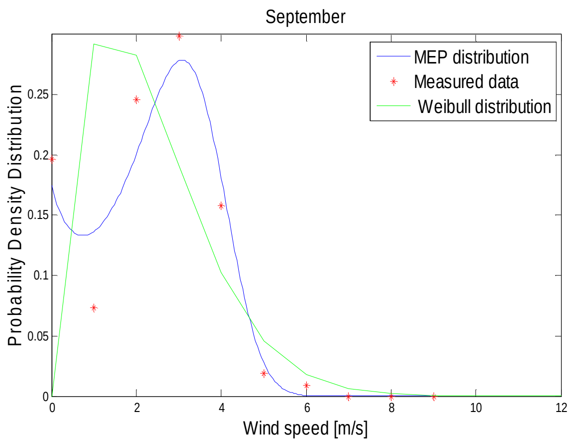


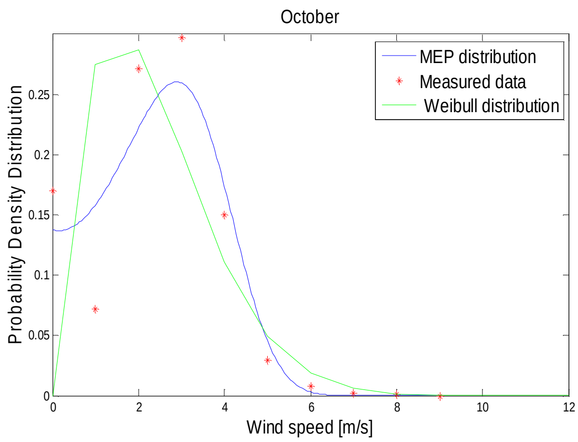

May
MEP distribution
Measured data
Weibull distribution
Probability Density Distribution
Wind speed [m/s]


June
MEP distribution
Measured data
Weibull distribution
Probability Density Distribution
Wind speed [m/s]


July
MEP distribution
Measured data
Weibull distribution
Probability Density Distribution
Wind speed [m/s]


August
MEP distribution
Measured data
Weibull distribution
Probability Density Distribution
Wind speed [m/s]


September
MEP distribution
Measured data
Weibull distribution
Probability Density Distribution
Wind speed [m/s]


October
MEP distribution
Measured data
Weibull distribution
Probability Density Distribution
Wind speed [m/s]

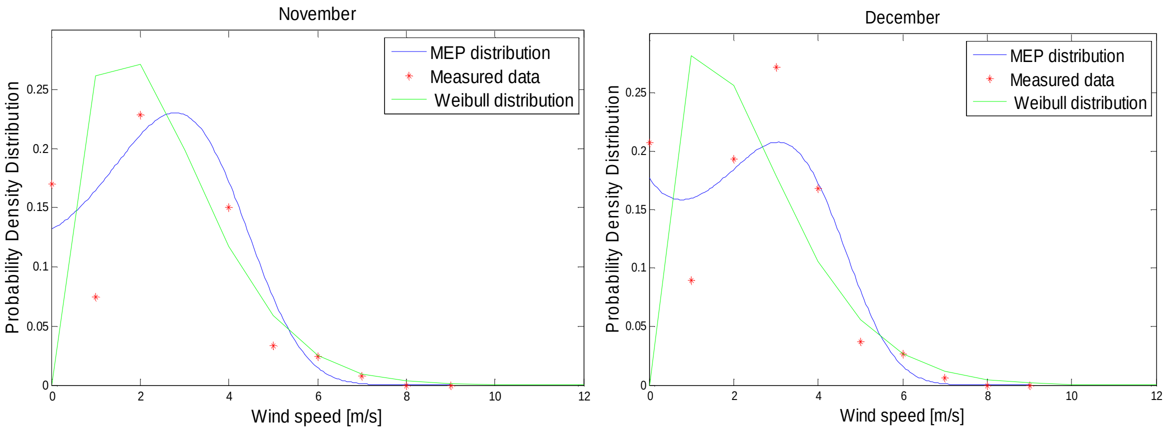


Figure 7:Wind speed frequency distributions for individual month based on 7-year data (2007-2013), in Bafoussam region, Cameroon ((a) January; (b) February; (c) March; (d) April; (e) May; (f)June; (g) July; (h) August; (i) September; (j) October; (k) November; (l) December.

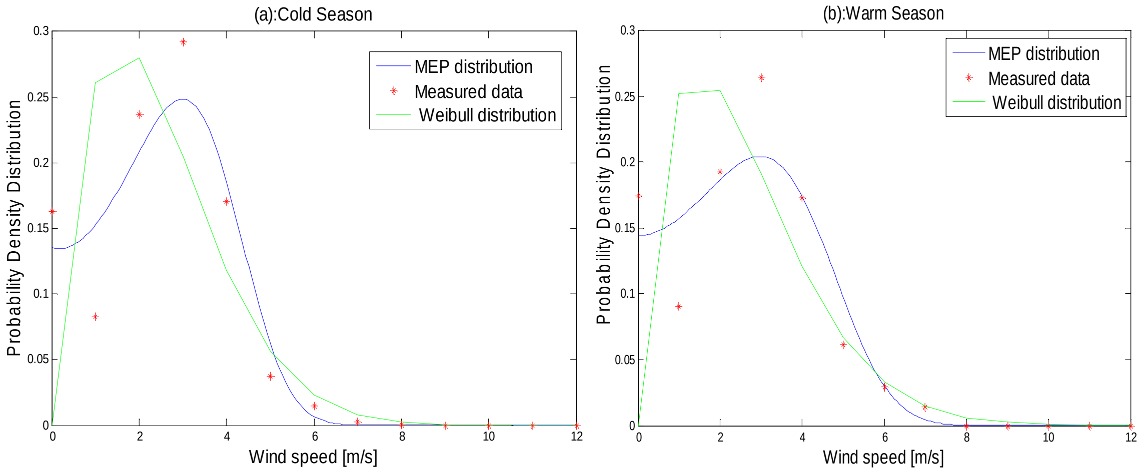


Figure 8: Wind direction frequency distributions for Cold Season (April-October), Warm Season (November-March) based on 7-year data (2007-2013), in Bafoussam region, Cameroon ((a) Cold Season; (b) Warm Season.

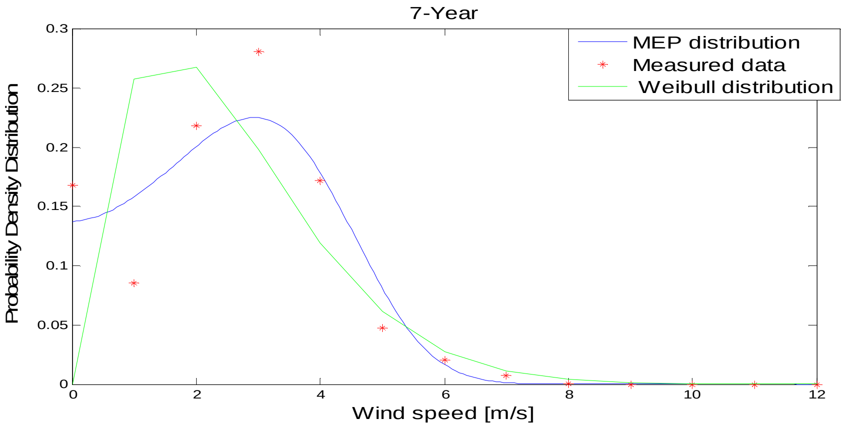


Figure 9: Wind speed frequency distributions for overall seven years (2007-2013), in Bafoussam region, Cameroon.