Journal of Fundamental and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

PERFORMANCE ANALYSIS OF METHODS FOR ESTIMATING WEIBULL PARAMETERS FOR WIND SPEED DISTRIBUTION IN THE DISTRICT OF MAROUA

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Received: 23 April 2014 / Accepted: 5 October 2014 / Published online: 31 December 2014

ABSTRACT

In this study, five numerical Weibull distribution methods, namely, the maximum likelihood method, the modified maximum likelihood method (MLM), the energy pattern factor method (EPF), the graphical method (GM), and the empirical method (EM) were explored using hourly synoptic data collected from 1985 to 2013 in the district of Maroua in Cameroon. The performance analysis revealed that the MLM was the most accurate model followed by the EPF and the GM. Furthermore, the comparison between the wind speed standard deviation predicted by the proposed models and the measured data showed that the MLM has a smaller relative error of -3.33% on average compared to -11.67% on average for the EPF and -8.86% on average for the GM. As a result, the MLM was precisely recommended to estimate the scale and shape parameters for an accurate and efficient wind energy potential evaluation.

Keywords: empirical method; energy pattern factor method; graphical method; maximum likelihood method; modified maximum likelihood method; wind speed.

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1. INTRODUCTION

Off-grid areas in the district of Maroua are endlessly dealing with many difficulties in their quest to improve the welfare of their inhabitants, one of which is the lack of access to local sustainable energy solutions. Delivering such energy solutions through small-scale Wind Energy Conversion Systems (WECS), including water pumping is vital if the district of Maroua is to move to towards the development of the agro-pastoral sector, the improvement of access to drinking water and thus better control the spread of the cholera epidemic and other water-borne diseases and the improvement of the living standard among rural populations. Given a good quality wind site, accessing to clean water is best achieved through pumping from underground water aquifers rather than using surface water sources, which are often polluted [1]. As a random phenomenon, wind speed is the most significant parameter of the wind energy. Therefore an accurate determination of the probability distribution of wind speed is essential for predicting the energy output of a WECS. In the last few years, researches in the wind engineering field and wind energy industry have devoted to the development of suitable predictive models to describe wind speed frequency distribution. The two-parameter Weibull Probability Density Function (PDF) has been used to represent wind speed distributions for applications in wind loads studies [2]. In addition, the Weibull PDF has been found as a useful and appropriate method of computing power output from wind-powered generators and applied to estimate potential power output at various sites across the continental United States [3]. In a study, Lysen [4] stated that the Weibull PDF showed its usefulness when the wind data of one reference station were used to predict the wind regime in the surroundings of that station. Patel [5] claimed variations in wind speed are best described by the Weibull PDF with two parameters. There seems to be a compromise in the literature that the Weibull PDF with two parameters, the dimensionless shape parameter k, and the scale parameter C, is a good quality probabilistic model for wind speed at one location. It is obvious that the more appropriate Weibull estimation method shall provide accurate and efficient evaluation of wind energy potential. In this regard, a number of studies have been carried out by various researchers in order to assess wind energy potential by using the Weibull PDF [6; 7; 8; 9]. Various methods have been effectively experimented for estimating the shape and scale parameters and the suitability of each method ranged according to the sample data distribution, which is basically location specific. In the present study, five numerical methods, namely, maximum likelihood method, the modified maximum likelihood method, energy pattern factor method, graphical method, and empirical method are explored and their suitability compared for the district of Maoua located in the Far North Region of Cameroon. The data collected for this study, were up to three times-a-day synoptic observations during the period from 1985 to 2013. The aim of this work was to select a method that gives more accurate estimation for the Weibull parameters at this location in order to reduce uncertainties related to the wind energy output calculation from any Wind Energy Conversion Systems (WECS).

2. MATERIALS AND METHODS

2.1. Data source

The data provided for the study were up to three times-a-day, randomly measured synoptic observations during the period from 1985 to 2013. The synoptic station is located as described by the geographical coordinates in the table 1. The table 2 shows the monthly mean wind speed.

Table 1. Geographical coordinates of the study area

Variable	**Value**
Latitude	12°34’56” N
Longitude	14°19’39” E
Anemometer Height	10 meters height above ground level
Elevation	395 meters above sea level

Table 2. Mean wind speed and wind speed standard deviation

Months	**Mean Wind Speed V (m/s)**	**Standard Deviation σ (m/s)**
January	2.821	1.293
February	2.996	1.438
March	3.027	1.316
April	2.927	1.208
May	2.833	1.528
June	2.841	1.514
July	2.707	1.419
August	2.606	1.340
September	2.624	1.384
October	2.542	0.964
November	2.619	1.025
December	2.734	1.156
Yearly Average	2.773	1.275

2.2. Measured wind speed probability distributions

In a study, Lysen [3] quoted that to determine frequency distribution of the wind speed, we must first divide the wind speed domain into a number of intervals, mostly of equal width of 1 m/s or 0.5 m/s. As a result, for a suitable statistical analysis, the wind speed data in time series format were transformed into frequency distribution format. In this process, the wind speeds were grouped into class interval and the mean wind speed defined for each class as illustrated in the table 3. Based on the wind speed classes, the frequency distribution of the measured wind speed was established and plotted as shown by the figure 1 while the cumulative frequency distribution of the measured wind speed displayed in the figure 2.

Table 3. Wind Speed Classes

Class	Range (m/s)	Mean Wind Speed ($\bar{v}$ (m/s))
1	$0 < v < 1$	0.5
2	$1 \le v < 2$	1
3	$2 \le v < 3$	2
4	$3 \le v < 4$	3
5	$4 \le v < 5$	4
6	$5 \le v < 6$	5
7	$6 \le v < 7$	6
8	$7 \le v < 8$	7
9	$8 \le v < 9$	8
10	$9 \le v$	9

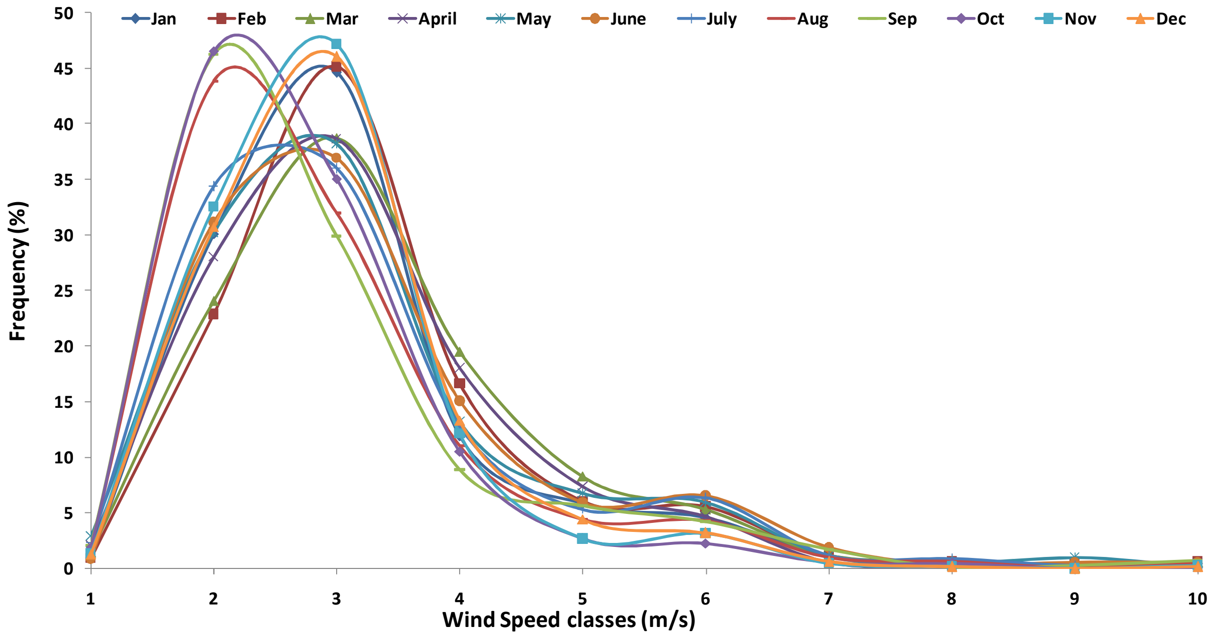

Fig.1. Frequency distribution of measured daily wind speed.

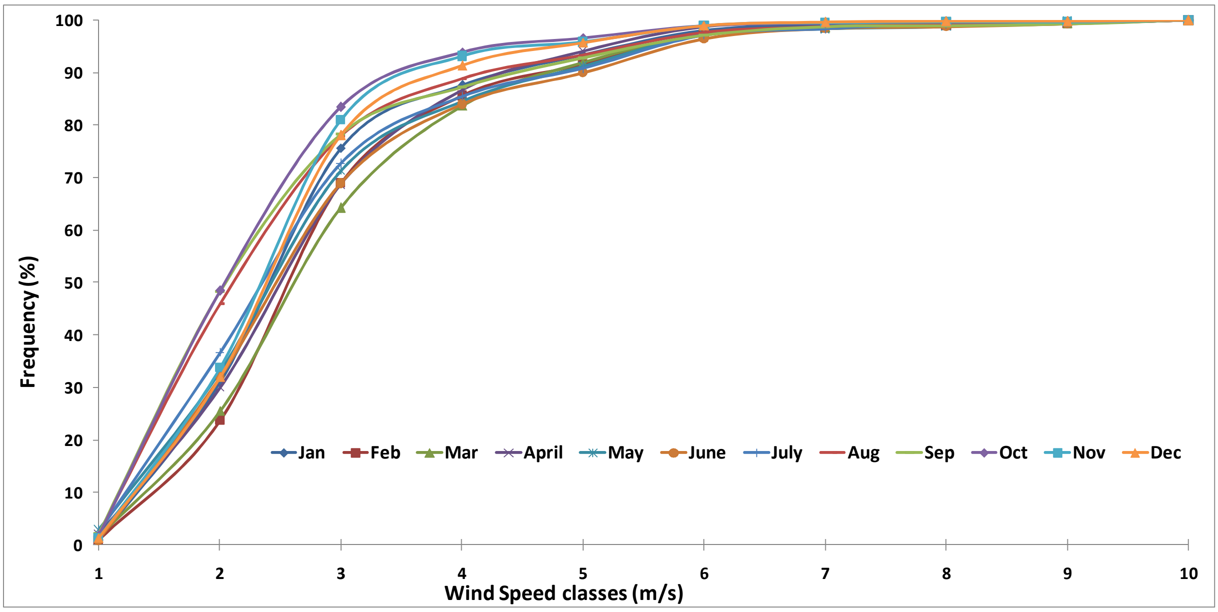

Fig.2. Cumulative Frequency distribution of measured daily wind speed.

2.3. Methods to estimate Weibull parameters

The variation in wind speed are most often described by the Weibull PDF with two parameters, the dimensionless Weibull shape parameter k, and the Weibull scale parameter C which have reference values in the units of wind speed. The PDF function $f(V)$ is given by the following [4; 10; 11; 12]:

$$f(V) = (k/C).(V/C)^{k-1}.\exp(-(V/C)^k) \quad (1)$$

Where: $f(V)$ = probability of observing wind speed V

V = wind speed $[m/s]$

C = Weibull scale parameter $[m/s]$

k = Weibull shape parameter

The corresponding cumulative distribution function is given by:

$$F(V) = 1 - \exp(-(V/C)^k) \quad (2)$$

To estimate the dimensionless shape k, and the scale C, parameters of the Weibull distribution function, five methods have been computed.

2.4. Graphical method

The graphical method (GM) 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 [6; 11; 12]. The logarithmic transformation is the foundation of this method. By converting the equation (2) into logarithmic form, the following equation is obtained:

$$\ln[-\ln(1-F(V))] = k\ln(V) - k\ln(C) \quad (3)$$

The Weibull shape and scale parameters are estimated by plotting $ln(V)$ against $\ln[-\ln(1-F(V))]$ in which a straight line is determined. In order to generate the line of best fit, observations of calms should be omitted from the data. The Weibull shape parameter, k, is the slope of the line and the y-intercept is the value of the term $-kln(C)$.

2.5. Maximum Likelihood method

The Maximum Likelihood Estimation method (MLM) is a mathematical expression known as a likelihood function of the wind speed data in time series format. The MLM method is solved through numerical iterations to determine the parameters of the Weibull distribution. The shape factor k and the scale factor C are estimated by the following equations [6; 8]:

$$k = \left[\left(\sum_{i=1}^{n} {V_i}^k \ln(V_i)\right)/\left(\sum_{i=1}^{n} {V_i}^k\right) - \sum_{i=1}^{n} \ln(V_i)\ /n\right]^{-1} \quad (4)$$

$$C = \left(\frac{1}{n}\sum_{i=1}^{n} {V_i}^k\right)^{1/k} \quad (5)$$

Where: n = number of non zero data values

i = measurement interval

V_i = wind speed measured at the interval i $[m/s]$

2.6. Modified Maximum Likelihood method

The Modified Maximum Likelihood Estimation method (MMLM) is used only for wind speed data available in the Weibull distribution format. The MMLM method is solved through numerical iterations to determine the parameters of the Weibull distribution. The shape factor k and the scale factor c are estimated by the following equations: [6]:

$$k = \left[\left(\sum_{i=1}^{n} {V_i}^k \ln(V_i) f(V_i)\right)/\left(\sum_{i=1}^{n} {V_i}^k f(V_i)\right) - \left(\sum_{i=1}^{n} \ln(V_i) f(V_i)\right)\ /f(V \geq 0)\right]^{-1} \quad (6)$$

$$c = \left[(1/f(V) \geq 0) \sum_{i=1}^{n} {V_i}^k f(V_i)\right]^{1/k} \quad (7)$$

Where: $f(V_i)$ = Weibull frequency with which the wind speed falls within the interval i

$f(V \geq 0)$ = Probability of wind speed $V \geq 0$

2.7. Empirical method

The empirical method (EM) is considered a special case of the moment method, where the Weibull parameters k and C can be determined using average wind speed and standard deviation as follows [6].

$$k = (\sigma/\bar{V})^{-1.089} \quad (8)$$

$$C = \bar{V}/\Gamma(1 + 1/k) \quad (9)$$

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

Where: $\bar{V}$ = mean wind speed $[m/s]$

σ = standard deviation of the observed data $[m/s]$

2.8. Energy pattern factor method

The energy pattern factor method (EPF) is related to the averaged data of wind speed and is defined by the following equations [6; 13].

$$E_{pf} = \overline{V^3}/\bar{V}^3 = \left(\frac{1}{n}\sum_{i=1}^{n} \overline{V_i}^3\right)/\left(\frac{1}{n}\sum_{i=1}^{n} \overline{V_i}\right)^3 \quad (11)$$

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

Where: E_{pf} is the energy pattern factor.

The Weibull scale parameter C is determined using the following equation:

$$C = \left(\frac{1}{n}\sum_{i=1}^{n} \overline{V_i}^k\right)^{1/k} \quad (13)$$

The standard deviation σ of the observed data is determined using the equation [10]:

$$\sigma = C[\Gamma(1 + 2/k) - \Gamma^2(1 + 1/k)]^{1/2} \quad (14)$$

Where the standard gamma function is given by:

$$\Gamma(x) = \int_0^\infty t^{x-1} \exp(-t)\, dt \quad (15)$$

And the gamma function can be approximated [10]:

$$\Gamma(x) = (\sqrt{2\pi x})(x^{x-1})(e^{-x})\left(1 + \frac{1}{12x} + \frac{1}{288x^2} - \frac{139}{51840x^3} + \cdots\right) \quad (16)$$

2.9. Prediction Performance of the Weibull distribution model

The correlation coefficient R^2 and root mean square error (RMSE) analysis have been carried out in order to determine which one of the Weibull parameter calculation methods gives a better result. These parameters can be calculated from the following equations [11], [12]:

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N} (y_i - x_i)^2\right]^{1/2} \quad (17)$$

$$R^2 = \frac{\sum_{i=1}^{N}(y_i - z_i)^2 - \sum_{i=1}^{N}(y_i - x_i)^2}{\sum_{i=1}^{N}(y_i - z_i)^2} \quad (18)$$

Where: y_i is the actual data, x_i is the predicted data using the Weibull distribution, z is the predicted data using the Weibull distribution, N is the number of observations;

3. RESULTS

For each of the five numerical methods considered in the analysis, the table 4 illustrates the monthly and yearly average of the standard deviation as well as the mean wind speed. The Weibull distribution functions for the five numerical methods, describing the wind speed frequency against the mean wind speed for the actual data on a monthly basis from 1985 to 2013, are presented in the figures 3 to 14. In these figures, the proposed methods are plotted alongside the measured wind speed frequencies. Subsequently, the tables 5 to 17 show the monthly and yearly average performance of the Weibull distribution models. The table 18 illustrates the comparison between the wind speed standard deviation predicted by the methods and the measured data. It is important to notice that the standard deviation of the measured data is the same as the standard deviation obtained using the empirical method as the same formula is used. Lastly, the Performance ranking for the proposed the Weibull distribution models are summarized in the table 19.

Table 4. Mean wind speed and wind speed standard deviation

	MLM	MMLM	GM	EM	EPF	Mean Wind Speed
Month	σ	σ	σ	σ	σ	V
January	1.371	1.368	1.452	1.293	1.622	2.821
February	1.486	1.481	1.594	1.438	1.728	2.996
March	1.388	1.387	1.463	1.316	1.507	3.027
April	1.244	1.245	1.298	1.208	1.295	2.927
May	1.509	1.502	1.625	1.528	1.612	2.833
June	1.500	1.493	1.609	1.514	1.620	2.841
July	1.410	1.405	1.518	1.419	1.511	2.707
August	1.336	1.332	1.440	1.340	1.462	2.606
September	1.373	1.367	1.486	1.384	1.544	2.624
October	1.091	1.092	1.140	0.964	1.149	2.542
November	1.084	1.086	1.145	1.025	1.128	2.619
December	1.182	1.183	1.245	1.156	1.226	2.734
Yearly Average	1.318	1.316	1.388	1.275	1.424	2.773

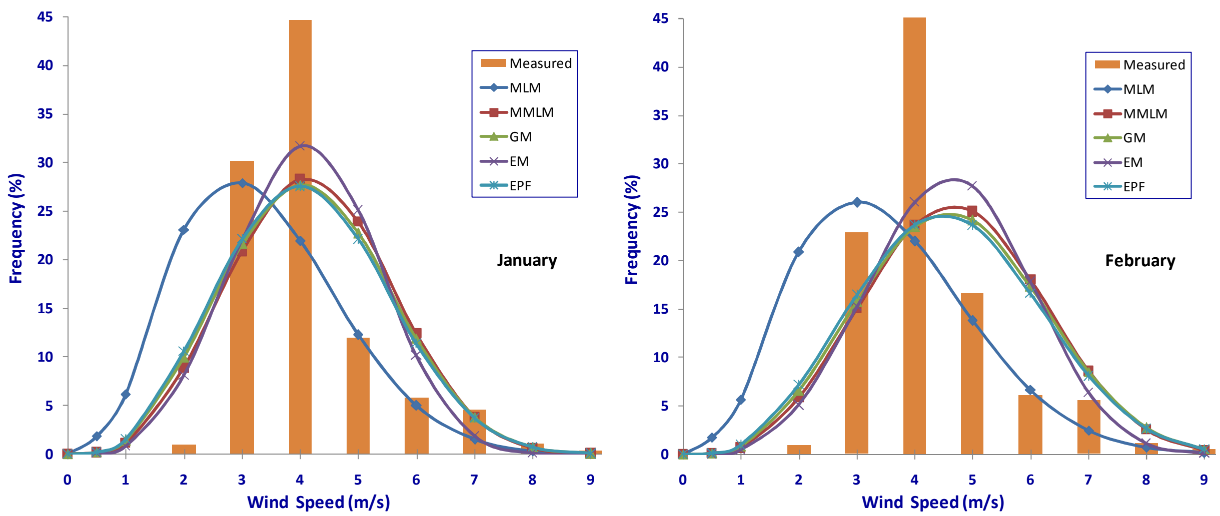

Fig.3. Monthly Weibull distribution for the five models for January and February.

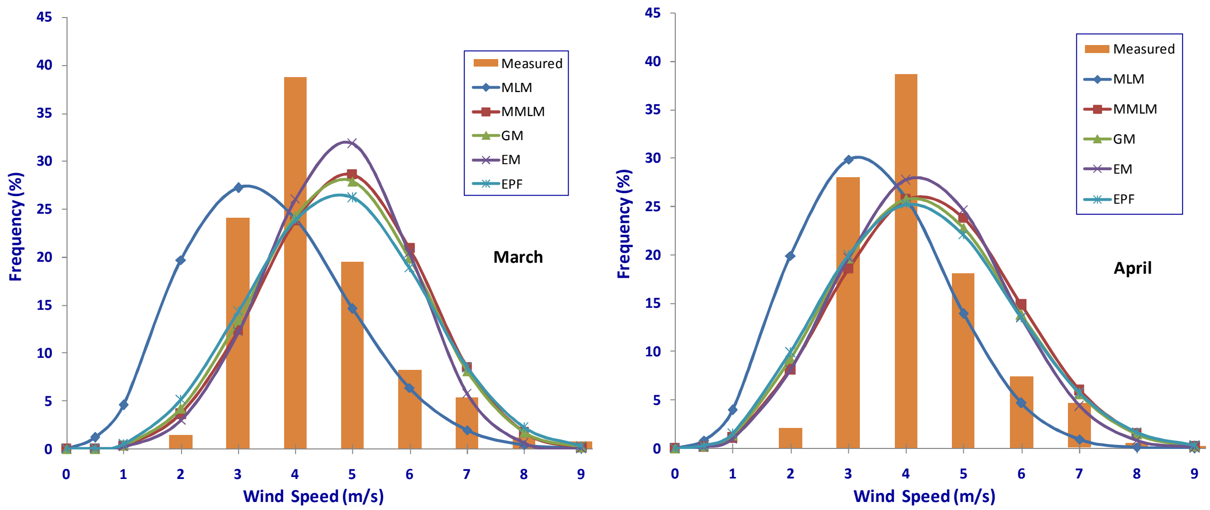

Fig.4. Monthly Weibull distribution for the five models for March and April.

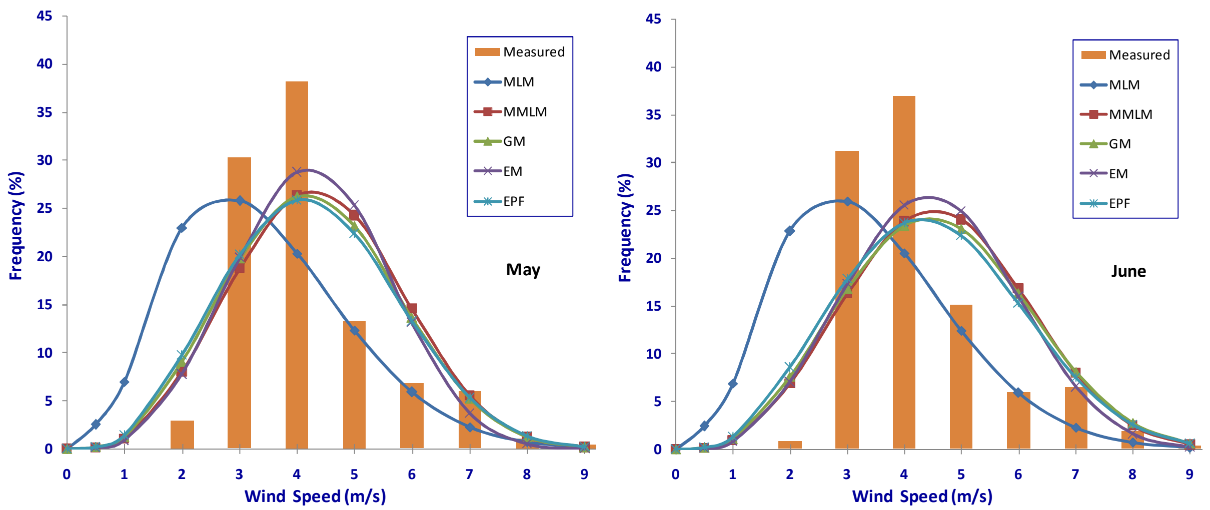

Fig.5. Monthly Weibull distribution for the five models for May and June.

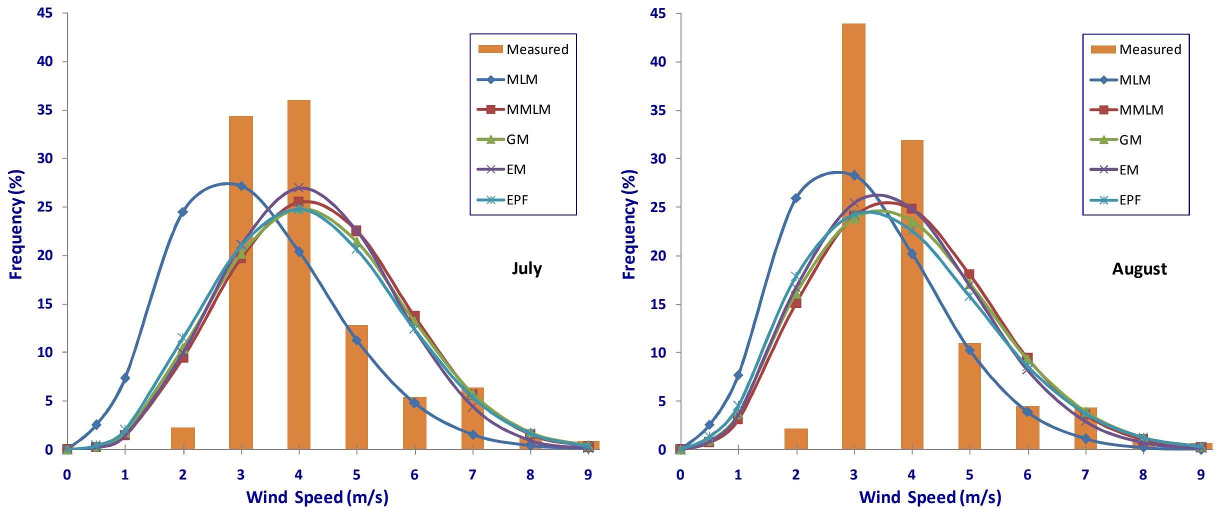

Fig.6. Monthly Weibull distribution for the five models for July and August.

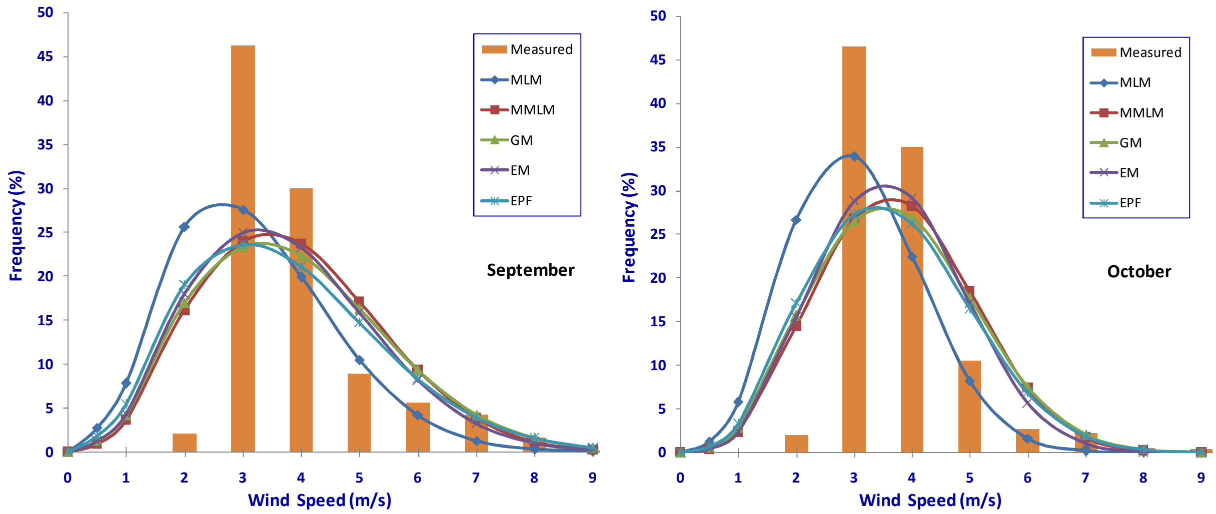

Fig.7. Monthly Weibull distribution for the five models for September and October.

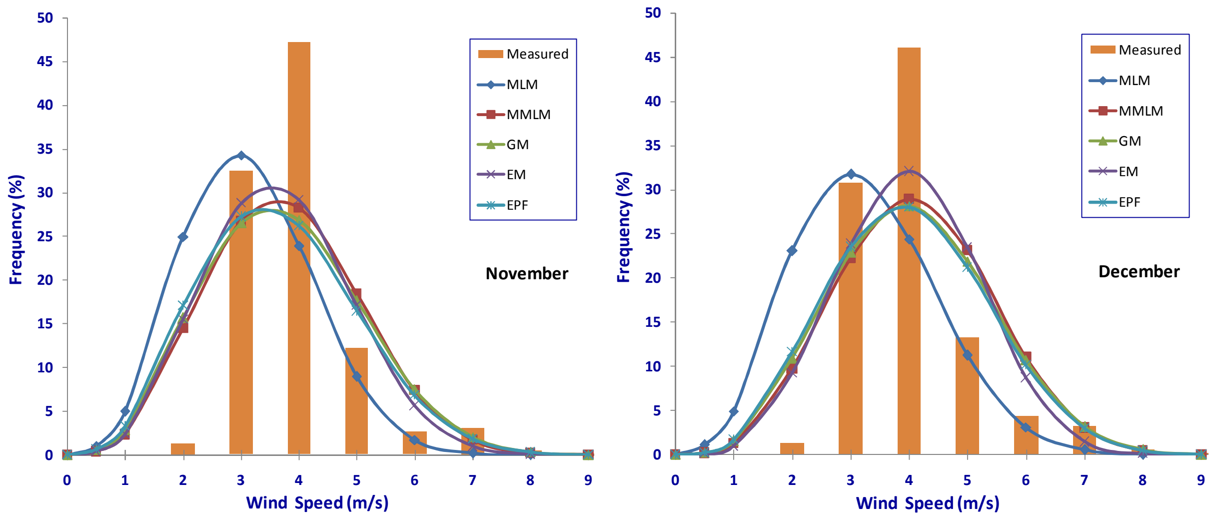

Fig.8. Monthly Weibull distribution for the five models for November and December.

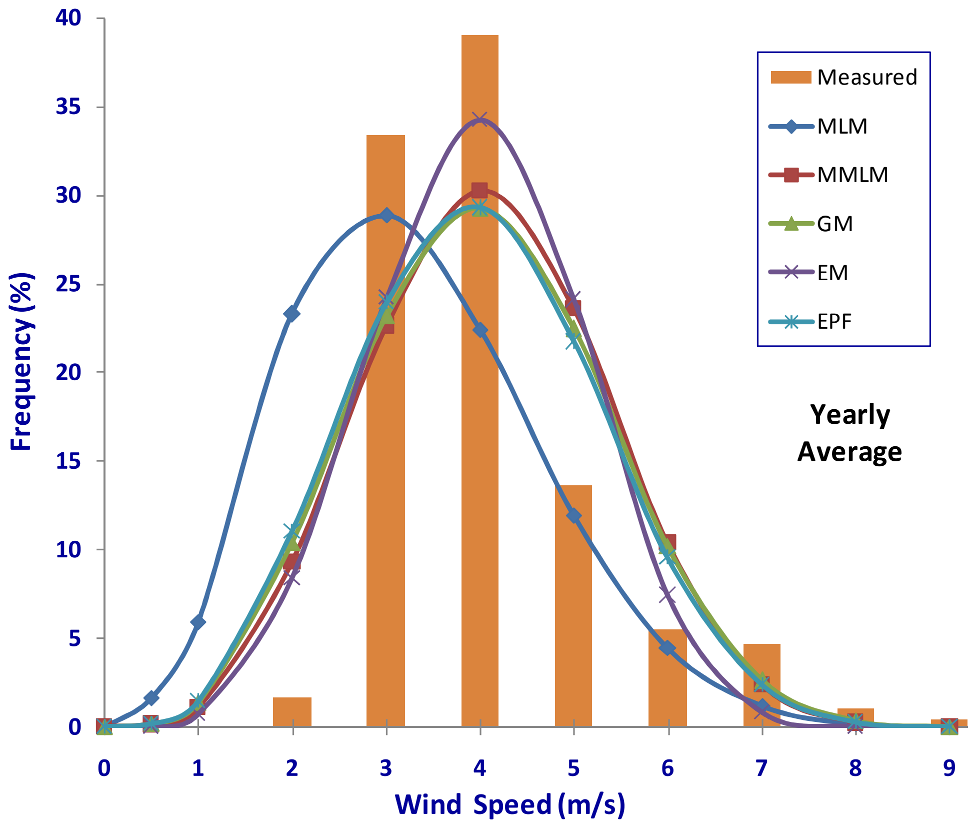

Fig.9. Yearly average Weibull distribution for the five models.

Table 5. Performance of the Weibull distribution models for the month of January

	Numerical methods	Weibull parameters		Statistical tests	
		Scale C	Shape k	RMSE	R^2
January	MLM	3.167	2.155	0.182729	0.995503
	MMLM	4.144	3.067	0.206514	0.994256
	GM	4.090	2.932	0.204045	0.994392
	EM	4.014	3.389	0.212342	0.993927
	EPF	4.044	2.876	0.202976	0.994451

Table 6. Performance of the Weibull distribution models for the month of February

	Numerical methods	Weibull parameters		Statistical tests	
		Scale C	Shape k	RMSE	R^2
February	MLM	3.373	2.113	0.170056	0.996559
	MMLM	4.699	3.138	0.199094	0.995284
	GM	4.665	3.011	0.196800	0.995392
	EM	4.566	3.456	0.204614	0.995019
	EPF	4.602	2.935	0.195360	0.995459

Table 7. Performance of the Weibull distribution models for the month of March

	Numerical methods	Weibull parameters		Statistical tests	
		Scale C	Shape k	RMSE	R^2
March	MLM	3.405	2.305	0.161570	0.996959
	MMLM	4.798	3.665	0.197384	0.995461
	GM	4.738	3.535	0.195243	0.995559
	EM	4.668	4.039	0.203402	0.995180
	EPF	4.720	3.298	0.191054	0.995747

Table 8. Performance of the Weibull distribution models for the month of April

	Numerical methods	**Weibull parameters**		**Statistical tests**	
		Scale C	**Shape k**	**RMSE**	**R^2**
April	MLM	3.298	2.518	0.175980	0.996133
	MMLM	4.373	2.960	0.190874	0.995450
	GM	4.283	2.846	0.188287	0.995573
	EM	4.239	3.114	0.193900	0.995305
	EPF	4.261	2.753	0.186139	0.995673

Table 9. Performance of the Weibull distribution models for the month of May

	Numerical methods	**Weibull parameters**		**Statistical tests**	
		Scale C	**Shape k**	**RMSE**	**R^2**
May	MLM	3.215	1.970	0.160162	0.996573
	MMLM	4.338	3.026	0.190690	0.995141
	GM	4.261	2.906	0.188390	0.995258
	EM	4.203	3.222	0.194398	0.994951
	EPF	4.229	2.812	0.186481	0.995354

Table 10. Performance of the Weibull distribution models for the month of June

	Numerical methods	**Weibull parameters**		**Statistical tests**	
		Scale C	**Shape k**	**RMSE**	**R^2**
June	MLM	3.223	1.990	0.158896	0.996648
	MMLM	4.607	2.988	0.188458	0.995284
	GM	4.592	2.857	0.185970	0.995408
	EM	4.469	3.091	0.190373	0.995188
	EPF	4.490	2.764	0.184098	0.995500

Table 11. Performance of the Weibull distribution models for the month of July

	Numerical methods	Weibull parameters		Statistical tests	
		Scale C	**Shape k**	**RMSE**	**R^2**
	MLM	3.069	2.018	0.166269	0.995941
	MMLM	4.276	2.813	0.189624	0.994721
July	GM	4.242	2.683	0.187003	0.994866
	EM	4.137	2.878	0.191008	0.994643
	EPF	4.152	2.601	0.185264	0.994961

Table 12. Performance of the Weibull distribution models for the month of August

	Numerical methods	Weibull parameters		Statistical tests	
		Scale C	**Shape k**	**RMSE**	**R^2**
	MLM	2.956	2.054	0.185273	0.994554
	MMLM	3.802	2.437	0.197476	0.993813
August	GM	3.776	2.297	0.193982	0.994030
	EM	3.650	2.400	0.196668	0.993864
	EPF	3.654	2.173	0.190499	0.994243

Table 13. Performance of the Weibull distribution models for the month of September

	Numerical methods	Weibull parameters		Statistical tests	
		Scale C	**Shape k**	**RMSE**	**R^2**
	MLM	2.978	2.011	0.186655	0.994550
	MMLM	3.768	2.310	0.196067	0.993987
September	GM	3.762	2.166	0.192338	0.994213
	EM	3.608	2.234	0.194201	0.994101
	EPF	3.606	2.016	0.187837	0.994481

Table 14. Performance of the Weibull distribution models for the month of October

	Numerical methods	Weibull parameters		Statistical tests	
		Scale C	Shape k	RMSE	R^2
October	MLM	2.861	2.487	0.214529	0.992316
	MMLM	3.660	2.760	0.219958	0.991923
	GM	3.628	2.608	0.216685	0.992161
	EM	3.521	2.830	0.221889	0.991780
	EPF	3.534	2.533	0.215095	0.992276

Table 15. Performance of the Weibull distribution models for the month of November

	Numerical methods	Weibull parameters		Statistical tests	
		Scale C	Shape k	RMSE	R^2
November	MLM	2.938	2.582	0.210656	0.993031
	MMLM	3.660	2.760	0.215223	0.992725
	GM	3.628	2.608	0.211654	0.992965
	EM	3.521	2.830	0.217016	0.992604
	EPF	3.534	2.533	0.209758	0.993090

Table 16. Performance of the Weibull distribution models for the month of December

	Numerical methods	Weibull parameters		Statistical tests	
		Scale C	Shape k	RMSE	R^2
December	MLM	3.082	2.471	0.199502	0.994282
	MMLM	4.031	3.044	0.213741	0.993436
	GM	3.982	2.904	0.211050	0.993600
	EM	3.902	3.316	0.218996	0.993109
	EPF	3.928	2.849	0.209972	0.993666

Table 17. Performance of the Weibull distribution models for the yearly average

	Numerical methods	Weibull parameters		Statistical tests	
		Scale C	Shape k	RMSE	R^2
Yearly Average	MLM	3.130	2.223	0.178758	0.995540
	MMLM	3.994	3.174	0.203103	0.994242
	GM	3.960	3.022	0.200267	0.994402
	EM	3.867	3.548	0.209996	0.993844
	EPF	3.900	2.981	0.199513	0.994444

Table 18. Comparison between the wind speed standard deviation predicted by the methods and the measured data

Months	MLM	MMLM	GM	EM	EPF
January	-6.07%	-5.82%	-12.31%	0.00%	-25.49%
February	-3.35%	-3.03%	-10.86%	0.00%	-20.18%
March	-5.47%	-5.37%	-11.18%	0.00%	-14.51%
April	-2.97%	-3.06%	-7.42%	0.00%	-7.21%
May	1.19%	1.66%	-6.41%	0.00%	-5.51%
June	0.94%	1.39%	-6.28%	0.00%	-6.96%
July	0.63%	1.02%	-6.95%	0.00%	-6.48%
August	0.27%	0.60%	-7.49%	0.00%	-9.14%
September	0.84%	1.23%	-7.33%	0.00%	-11.57%
October	-13.12%	-13.26%	-18.21%	0.00%	-19.16%
November	-5.78%	-5.97%	-11.69%	0.00%	-10.08%
December	-2.26%	-2.34%	-7.70%	0.00%	-6.06%
Yearly Average	-3.33%	-3.17%	-8.86%	0.00%	-11.67%

Table 19. Performance ranking for of the five Weibull distribution models

Months	MLM	MMLM	GM	EM	EPF
January	1	4	3	5	2
February	1	4	3	5	2
March	1	4	3	5	2
April	1	4	3	5	2
May	1	4	3	5	2
June	1	4	3	5	2
July	1	4	3	5	2
August	1	5	3	4	2
September	1	5	3	4	2
October	1	4	3	5	2
November	2	4	3	5	1
December	1	4	3	5	2
Yearly Average	1	4	3	5	2

4. DISCUSSIONS

4.1. Performance of the Weibull distribution models

As mentioned earlier, there is no doubt that the Weibull PDF with two parameters, the dimensionless shape parameter k, and the scale parameter C, is a good quality probabilistic model for wind speed in the district of Maroua. Therefore, the proposed five methods are effective in evaluating the parameters of the Weibull distribution for the available data. Obviously, the more suitable Weibull estimation method shall provide accurate and efficient evaluation of wind energy potential. The performance of the proposed five models were carried out based on the correlation coefficient $\mathbf{R^2}$ and the root mean square error (RMSE) analysis in order to determine which one of the Weibull parameter calculation methods gives a better result. The best parameters estimation shall contain the lowest value of RMSE and the highest value of R^2. As a result, the performance rankings for the five Weibull distribution models are provided in the Table 19. Overall, the maximum likelihood method is the most accurate model followed by the energy pattern factor method and the graphical method. The least precise models are the empirical method followed by the modified maximum likelihood method. Furthermore, it is observed that the values of RMSE, and R^2, have magnitudes very close to each other for all the numerical methods used for the collected data. The table 18 illustrates the comparison between the wind speed standard deviation predicted by the five models and the measured data. It can be noticed that the maximum likelihood method has a smaller relative error of **-3.33%** on average compared to **-11.67%** for the energy Pattern Factor method. The standard deviation formula for the measured data is the same as the standard deviation formula for the empirical method, hence the relative error of **0.00%** for the empirical method.

4.2. Weibull distribution model parameters C and k

The Weibull shape k parameter indicates the breadth of a distribution of wind speeds. Lower k values mean that winds tend to vary over a large range of speeds while higher k values correspond to wind speeds staying within a narrow range. When considering the maximum likelihood method as the most accurate Weibull distribution model, it's observed that Weibull k values range from **1.970** in the month of May to **2.582** in the month of November. Typical Weibull k value for most wind conditions ranges from **1.500** to **3.000** [14]. On the other hand, the Weibull scale C parameter shows how "windy" a location is or, in other words, how high the annual mean speed is. When considering the maximum likelihood method as the most accurate Weibull distribution model, it's as well observed that Weibull C values vary from **2.861** of October to **3.405** of March. These two Weibull parameters determine the wind speed for optimum performance of a WECS as well as the speed range over which it's expected to operate.

5. CONCLUSION

Based on the data collected in the district of Maroua, the aim of this work was to provide an insightful analysis to engineers when selecting a method that gives more accurate estimation for the Weibull parameters in order to reduce uncertainties related to the wind energy output calculation from any WECS.

The following main conclusions can be drawn from the present study:

1. Monthly and average yearly performances of the Weibull distribution for the five proposed models were carried out based on the correlation coefficient R^2 and root mean square error (RMSE);

2. The proposed five methods are effective in evaluating the parameters of the Weibull distribution for the available data since the values of RMSE, and R^2 have magnitudes very close to each other for the collected data in the district of Maroua, Cameroon;
3. The performance comparison of the proposed methods established that the most accurate models are the maximum likelihood method followed by the energy pattern factor method and the graphical method. The least precise models are the empirical method followed by the modified maximum likelihood method.
4. The comparison between the wind speed standard deviation predicted by the models and the measured data showed a smaller relative error using the maximum likelihood method than using the energy pattern factor method or the graphical method, the most accurate models;
5. The results therefore, strongly suggest, based on the collected data in the district of Maroua, that the maximum likelihood method is more reliable in estimating Weibull shape and scale parameters. Consequently, the yearly average for the Weibull k value is **2.222** while the yearly average for the Weibull C value is **3.130**.

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How to cite this article:
Kidmo Kaoga D. Raidandi D. Yamigno Doka S. Djongyang N. Performance analysis of two-parameter weibull distribution methods for wind energy applications in the district of Maroua, Cameroon. J Fundam Appl Sci. 2014, *6(2), 153-174.*