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Performance Assessment of Two-parameter Weibull Distribution Methods for Wind Energy Applications in the District of Maroua in Cameroon

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Abstract

Wind speed is the most important parameter to be considered when designing wind energy conversion systems (WECS), since its probability density distribution greatly affects the performance. In this paper, five numerical methods were analysed and their performance evaluated for effectiveness in determining the parameters for the Weibull distribution. Twenty eight years (1985 – 2013) daily mean wind speed data at a height of 10 meters for the district of Maroua in Cameroon were subjected to different statistical tests. The performance analysis showed that the values of the root mean square error (RMSE), Chi-square (χ^2) and correlation coefficient R^2 analysis had magnitudes very close to each other. As a result, the Energy Pattern Factor method (EPF) proved to be the more accurate two-parameter Weibull distribution method. The graphical method (GM) ranked 2nd while the maximum likelihood method (MLM) ranked 3rd. The Modified Maximum Likelihood Method (MMLM) and Empirical method (EM) ranked 4th and 5th respectively.

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To further evaluate the performance of the methods, a first comparison between the monthly mean wind speeds predicted by the Weibull distribution methods and the measured data showed 0.00% error for the EPF and EM while the errors ranged between -0.5625% and 0.6123% for the MLM. Greater errors were found using the MMLM (3.8863% to 5.6126%) and the GM (2.9014% to 6.0910%). A second comparison between the standard deviation predicted by the Weibull methods and the measured data revealed larger errors using the EPF (4.1343% to 19.7227%). The errors were found to lie between 4.8493% to 10.2979% and -2.8609% to 5.3593% for the GM and MMLM respectively. The EM and MLM delivered smaller errors ranging between -7.6996% to -0.4456% and -2.3660% to 5.1893% respectively. As a result, this study recommends the EPF and MLM for use to provide more accurate estimation for the Weibull parameters.

Keywords: Empirical method; Energy pattern factor method; graphical method; maximum likelihood method; modified maximum likelihood method; wind speed; Weibul distribution.

1. Introduction

Globally, most promising renewable sources of energy with near-zero emissions have raised the need to enhance local energy supply. Environmentally friendly sources of energy, such as wind, solar, biomass and hydro have been the focus of energy development and planning at national and regional levels. In Cameroon, the hydro source of energy is producing more than 75% of energy for the national electricity production [1]. However, in remote and off-grid areas, the need to enhance local and economically attractive energy supply while generating and consuming energy harmless to the environment, have driven the trend towards diversification of sources of energy. According to the national energy master plan, wind is a major alternative energy source for the district of Maroua. As such, efforts have been made to measure and assess wind speed for power generation. Wind energy as a renewable energy source has emerged as one of the friendliest sources of energy as it does not require any fuel to burn and hence does not produce any kind of pollutant [2]. As a random phenomenon, wind speed is the most significant parameter of the wind energy. Therefore to assess wind energy potential and performance of Wind turbines, wind speed prediction is a significant factor. In recent times, suitable predictive models to describe wind speed frequency distribution have been developed. The two-parameter Weibull Probability Density Function (PDF) has been used to represent wind speed distributions for applications in wind loads studies [3]. Moreover, the typical two-parameter Weibull has been accepted as a flexible distribution that is useful for describing unimodal frequency distributions of wind speeds at many sites [4]. According to current studies [5-6] the use two-parameter Weibull (PDF) distribution to represent wind data instead of the measured data in time-series format, has shown that estimated wind energy is highly accurately for estimating the wind energy. 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 a given 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 [7-10]. Various methods have been effectively experimented for estimating the shape and scale parameters and the suitability of each method varied according to the sample data distribution, which is basically location specific. In the present study, five numerical methods, namely the maximum likelihood method (MLM), the modified maximum likelihood method (MMLM), the energy pattern factor method (EPF), the graphical method (GM), and the empirical method (EM) are explored and their suitability compared using time-series of measured hourly daily wind speed data for the period between 1985 and 2013 collected in the district of Maroua, located in the Far North Region of Cameroon. The aim of this work was to select a method that gives more accurate estimation for the Weibull parameters in order to reduce uncertainties related to the wind energy output calculation.

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 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

Period	**Mean Wind Speed $\bar{V}$ (m/s)**	**Standard Deviation σ (m/s)**
Jan	2.820988	1.302213
Feb	2.995890	1.450417
Mar	3.026996	1.323906
Avril	2.926870	1.213606
May	2.832730	1.545203
June	2.841391	1.531449
July	2.706503	1.434561
Aug	2.606455	1.353634
Sept	2.624117	1.399506
Oct	2.542248	1.038633
Nov	2.618549	1.028088
Dec	2.733899	1.161927
Whole year	2.773053	1.315262

2.2. Measured mean wind speed and standard deviation

The monthly mean wind speed $\bar{V}$ and the standard deviation σ of the time-series of measured hourly daily wind speed data are determined using the Eqs. 1 and 2 [5,11]:

$$\bar{V} = \frac{1}{N}\left(\sum_{i=1}^{N} V_i\right) \quad (1)$$

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

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

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

N = number of measured hourly daily wind speed data.

2.3. Measured wind speed probability distribution

In a study, Lysen [12] 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	$1 \leq V < 2$	1
3	$2 \leq V < 3$	2
4	$3 \leq V < 4$	3
5	$4 \leq V < 5$	4
6	$5 \leq V < 6$	5
7	$6 \leq V < 7$	6
8	$7 \leq V < 8$	7
9	$8 \leq V < 9$	8
10	$9 \leq V$	9

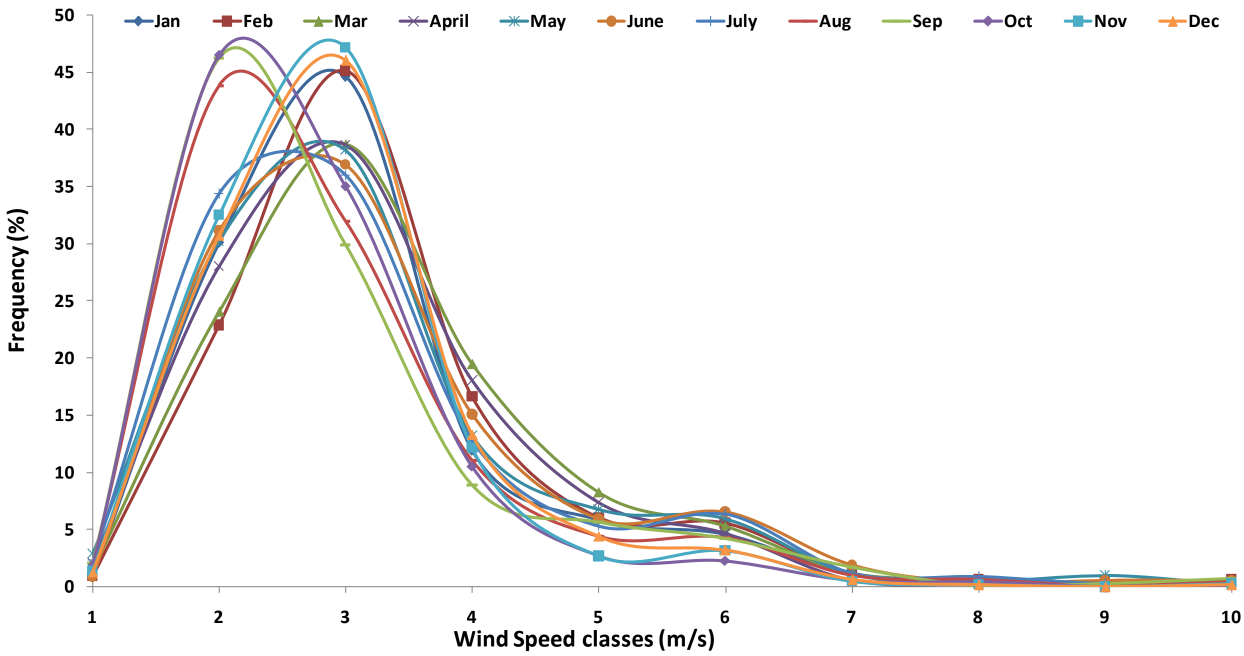

Fig. 1: Frequency distribution of measured daily wind speed.

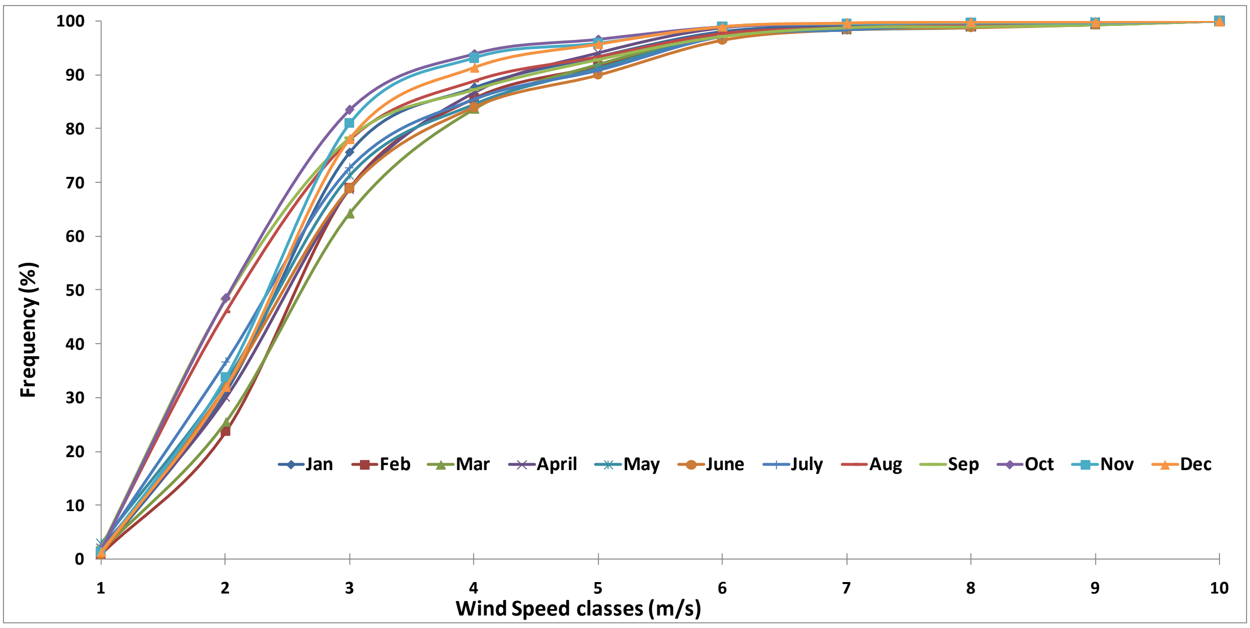

Fig. 2: Cumulative Frequency distribution of measured daily wind speed.

2.4. 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 Eqs. [11,13] :

$$f(V) = (k/C).(V/C)^{k-1}.\exp(-(V/C)^k) \qquad (3)$$

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:

$$F(V) = 1 - \exp(-(V/C)^k) \quad (4)$$

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

2.4.1. 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 [7,10,13]. The logarithmic transformation is the foundation of this method. By converting the eq. 4 into logarithmic form, the Eq. 5 is obtained:

$$\ln[-\ln(1 - F(V))] = kln(V) - kln(C) \quad (5)$$

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 $-kln(C)$.

2.4.2. 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 was used by Costa Rocha et al [7] quoting Stevens and Smulders [14] in their study for the estimation of parameters of the Weibull wind speed distribution for wind energy utilization purposes. 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 Eqs. 6 and 7 [6,7,14,15] :

$$k = \left[\frac{\sum_{i=1}^{n} {V_i}^k \ln(V_i)}{\sum_{i=1}^{n} {V_i}^k} - \frac{\sum_{i=1}^{n} \ln(V_i)}{n}\right]^{-1} \quad (6)$$

$$c = \left(\frac{1}{n}\sum_{i=1}^{n} {V_i}^k\right)^{1/k} \quad (7)$$

Where: n = number of non zero data values;

i = measurement interval;

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

2.4.3. 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 [7,14]. The shape factor k and the scale factor c are estimated by the Eqs. 8 and 9.

$$k = \left[\frac{\sum_{i=1}^{n} {V_i}^k \ln(V_i) f(V_i)}{\sum_{i=1}^{n} {V_i}^k f(V_i)} - \frac{\sum_{i=1}^{n} \ln(V_i) f(V_i)}{f(V \geq 0)}\right]^{-1} \qquad (8)$$

$$c = \left[\frac{\sum_{i=1}^{n} {V_i}^k f(V_i)}{f(V) \geq 0}\right]^{1/k} \qquad (9)$$

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

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

2.4.4. Empirical Method

The Weibull parameters k and c for the empirical method (EM) are determined using average wind speed and standard deviation as follows [7]:

$$k = (\sigma/\bar{V})^{-1.089} \qquad (10)$$

$$C = \bar{V}/\Gamma(1 + 1/k) \qquad (11)$$

The standard deviation σ of the observed data is determined using the Eqs. 12 and 13.

$$\sigma = C[\Gamma(1 + 2/k) - \Gamma^2(1 + 1/k)]^{1/2} \qquad (12)$$

Where the standard gamma function is given by:

$$\Gamma(x) = \int_0^\infty t^{x-1} \exp(-t)\, dt \qquad (13)$$

The gamma function used by J.F. Manwell et al [16] quoting Jamil [17] is given by:

$$\Gamma(x) = \left(\sqrt{2\pi x}\right)(x^{x-1})(e^{-x})\left(1 + \frac{1}{12x} + \frac{1}{288x^2} - \frac{139}{51840\,x^3} + \cdots\right) \qquad (14)$$

2.4.5. Energy Factor Method

The energy pattern factor method (EPF) is related to the averaged data of wind speed and is defined by the Eqs. 15, 16 and 17 [7,18].

$$E_{pf} = \overline{V^3}/\bar{V}^3 = \left(\frac{1}{n}\sum_{i=1}^{n} \overline{V_i}^3\right)/\left(\frac{1}{n}\sum_{i=1}^{n} \overline{V_i}\right)^3 \qquad (15)$$

$$k = 1 + 3.69/(E_{pf})^2 \qquad (16)$$

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

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

$$C = \left(\frac{1}{n}\sum_{i=1}^{n} \overline{V}_i^{\,k}\right)^{1/k} \qquad (17)$$

2.5. Prediction Performance of the Weibull distribution methods

In order to evaluate the performance of the five Weibull distributions methods, the correlation coefficient R^2, the root mean square error (RMSE) and the chi-square analysis have been carried out.

The RMSE parameter gives the deviation between the predicted and the experimental values, it should be as close to zero as possible, and it is expressed as [6,7]:

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2\right]^{1/2} \qquad (18)$$

Chi-square test returns the mean square of the deviations between the experimental and the calculated values for the distributions and it is expressed as [6,7]:

$$\chi^2 = \frac{\sum_{i=1}^{n}(y_i - x_i)^2}{N-n} \qquad (19)$$

The correlation coefficient R^2 shows the ability of the model, and the highest value it can get is 1. R^2 is determined by the Eq. 20 [6,7].

$$R^2 = \frac{\sum_{i=1}^{N}(y_i - z_i)^2 - \sum_{i=1}^{N}(y_i - x_i)^2}{\sum_{i=1}^{N}(y_i - z_i)^2} \qquad (20)$$

Where: y_i is the actual data, x_i is the predicted data using the Weibull distribution, z is the mean value of y_i, N is the number of all observed wind data and n is the number of constants used.

3. Results

For each of the five numerical methods considered in the analysis, figures 3 to 8 illustrate the Weibull PDF $f(V)$, versus the mean wind speed $\bar{V}$, for measured hourly daily wind speed data from January to December while figure 9 present the whole year Weibull PDF distribution describing the wind speed frequency against the mean wind speed for the actual data. It can be observed from these figures how the curves representing the Weibull PDF, for each of the proposed methods considered in the analysis, match the histograms of measured hourly daily wind speed data, illustrating the method that fits best to the measured wind speed data. Then, tables 4 to 15 show calculated monthly scale and shape parameters for each of the proposed Weibull PDF method in addition to statistical tests to assess the performance Weibull methods. Table 16 illustrates as well the values of the whole year scale and shape parameters and statistical tests. After that, table 17 gives details for the comparison between standard deviations predicted by the methods and the measured data. Finally, table 18 provides a comparison between the wind speed predicted by the methods and the measured data.

Table 4: Performance of the Weibull distribution methods for January

	Numerical methods	Weibull parameters		Statistical tests		
		Scale C	Shape k	RMSE	R^2	χ^2
	MLM	3.167057	2.154501	0.009924	0.999826	0.000297
	MMLM	3.319744	2.277131	0.010439	0.999817	0.000313
JAN	GM	3.300727	2.117000	0.009849	0.999827	0.000295
	EM	3.183528	2.315214	0.010524	0.999815	0.000315
	EPF	3.171558	1.798891	0.008463	0.999852	0.000254

Table 5: Performance of the Weibull distribution methods for February

	Numerical methods	Weibull parameters		Statistical tests		
		Scale C	Shape k	RMSE	R^2	χ^2
	MLM	3.372673	2.112601	0.008513	0.999881	0.000253
	MMLM	3.526429	2.228036	0.009013	0.999874	0.000267
FEB	GM	3.546943	2.067000	0.008468	0.999881	0.000251
	EM	3.382275	2.198496	0.008824	0.999876	0.000262
	EPF	3.367621	1.792688	0.007294	0.999898	0.000216

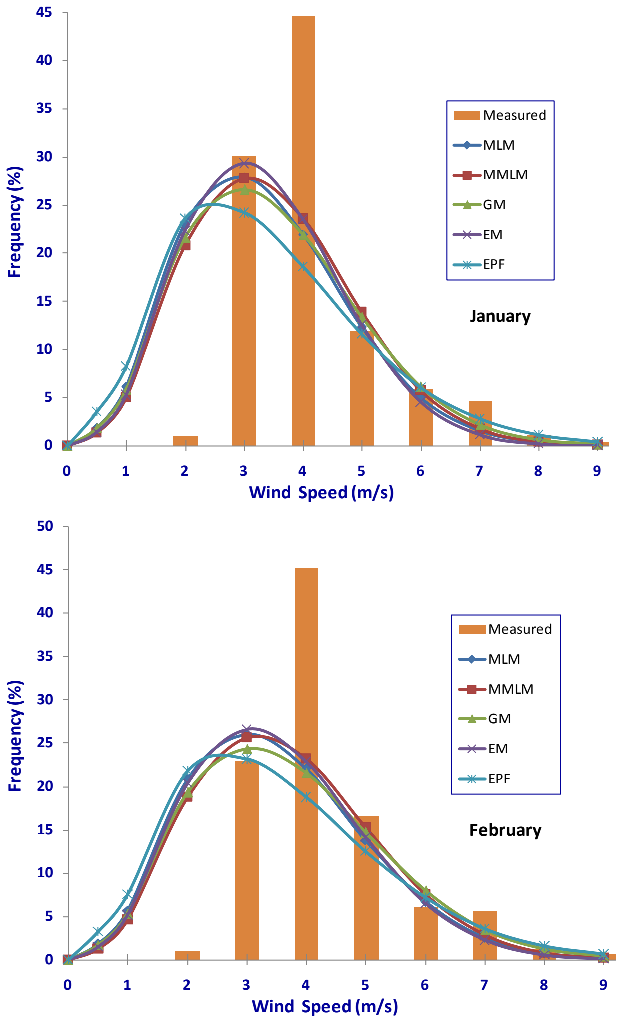

Fig. 3: Monthly Weibull distribution methods for January and February.

Table 6: Performance of the Weibull distribution methods for March

	Numerical methods	Weibull parameters		Statistical tests		
		Scale C	Shape k	RMSE	R^2	χ^2
	MLM	3.405027	2.304877	0.007431	0.999879	0.000213
	MMLM	3.551577	2.420468	0.007882	0.999872	0.000226
MAR	GM	3.537229	2.267000	0.007411	0.999880	0.000213
	EM	3.412546	2.454946	0.007890	0.999872	0.000226
	EPF	3.417216	2.110689	0.006825	0.999889	0.000196

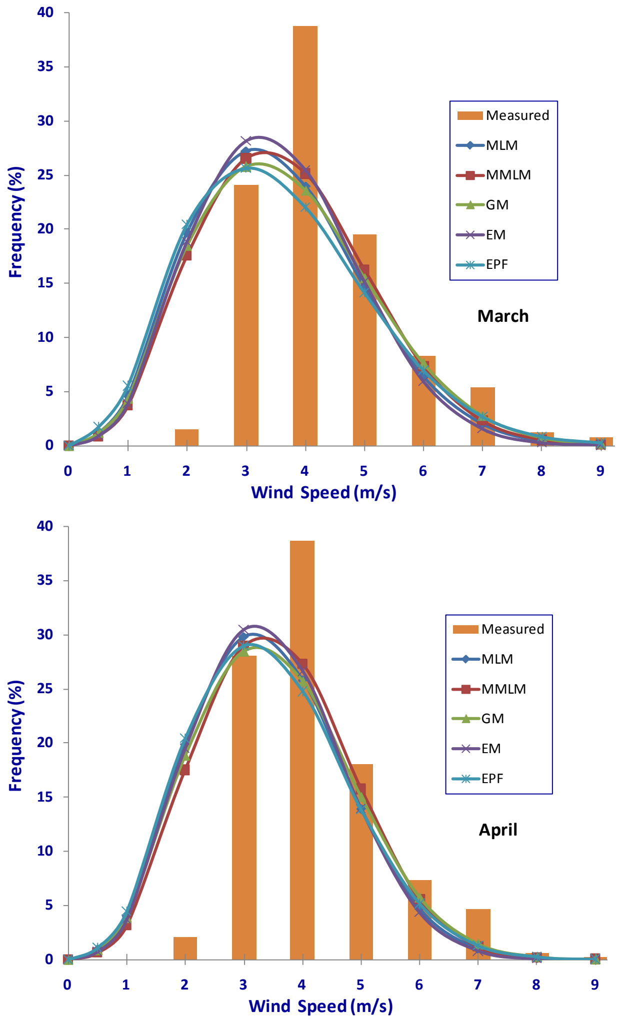

Fig. 4: Monthly Weibull distribution methods for March and April.

Table 7: Performance of the Weibull distribution methods for April

	Numerical methods	Weibull parameters		Statistical tests		
		Scale C	Shape k	RMSE	R^2	χ^2
	MLM	3.298310	2.518199	0.010205	0.999771	0.000340
	MMLM	3.439542	2.640307	0.010713	0.999760	0.000356
APR	GM	3.400194	2.484000	0.010159	0.999772	0.000338
	EM	3.294719	2.601391	0.010489	0.999765	0.000349
	EPF	3.301002	2.406683	0.009811	0.999780	0.000326

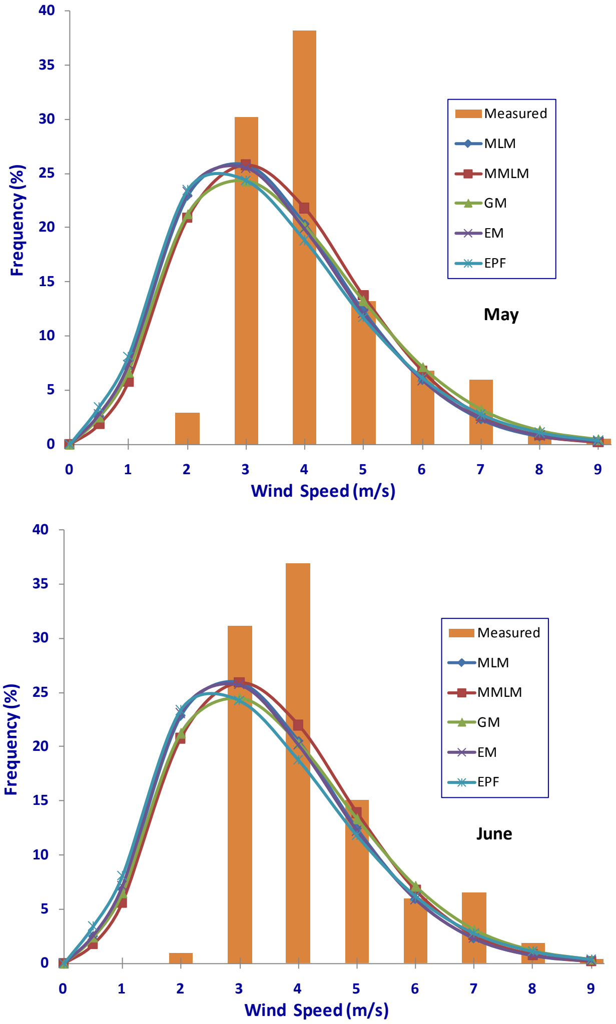

Fig. 5: Monthly Weibull distribution methods for May and June.

Table 8: Performance of the Weibull distribution methods for May

	Numerical methods	Weibull parameters		Statistical tests		
		Scale C	Shape k	RMSE	R^2	χ^2
MAY	MLM	3.214595	1.970459	0.007717	0.999903	0.000234
	MMLM	3.377673	2.091040	0.008241	0.999896	0.000250
	GM	3.390811	1.927000	0.007654	0.999903	0.000232
	EM	3.193322	1.931331	0.007554	0.999905	0.000229
	EPF	3.186493	1.819926	0.007107	0.999910	0.000216

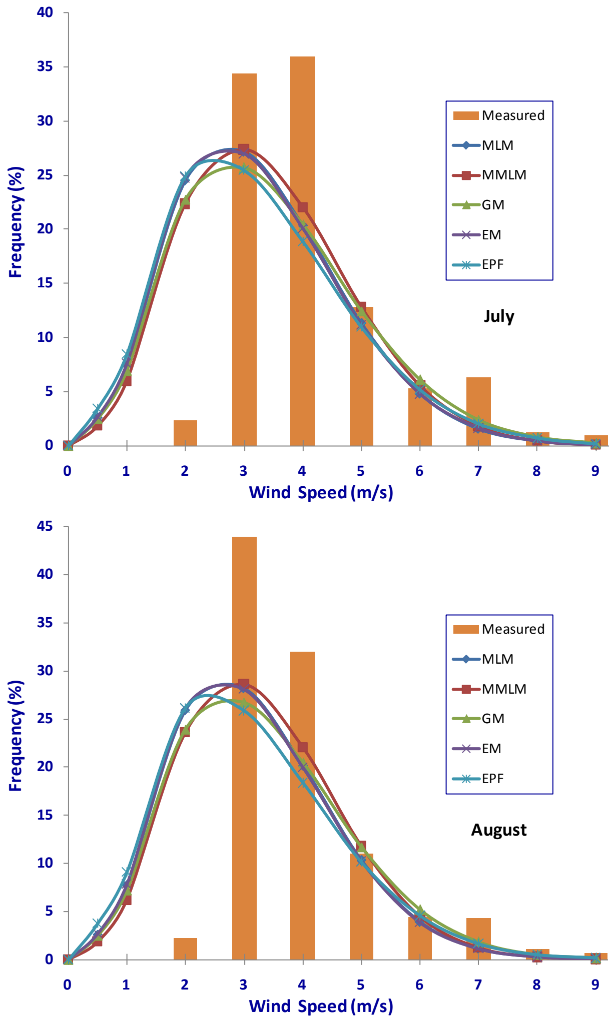

Fig. 6: Monthly Weibull distribution methods for July and August.

Table 9: Performance of the Weibull distribution methods for June

	Numerical methods	Weibull parameters		Statistical tests		
		Scale C	Shape k	RMSE	R^2	χ^2
	MLM	3.223307	1.989668	0.007952	0.999893	0.000253
	MMLM	3.385042	2.109890	0.008499	0.999886	0.000270
JUNE	GM	3.391433	1.948000	0.007893	0.999894	0.000251
	EM	3.204159	1.956651	0.007809	0.999895	0.000248
	EPF	3.195937	1.816178	0.007222	0.999903	0.000230

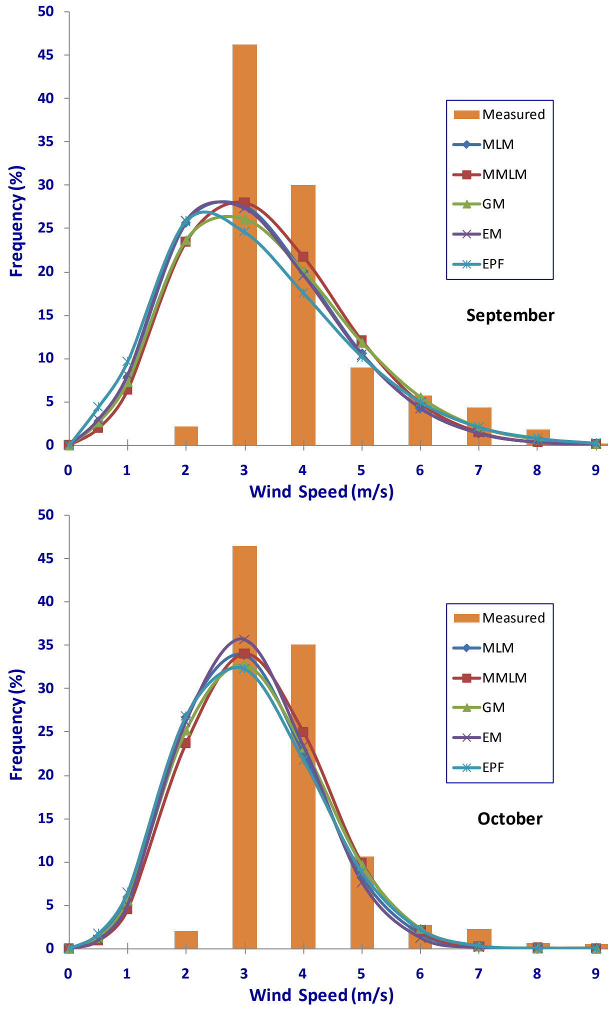

Fig. 7: Monthly Weibull distribution for the five models for September and October.

Table 10: Performance of the Weibull distribution methods for July

	Numerical methods	Weibull parameters		Statistical tests		
		Scale C	Shape k	RMSE	R^2	χ^2
	MLM	3.069389	2.017801	0.008777	0.999864	0.000281
	MMLM	3.229711	2.143512	0.009343	0.999856	0.000299
JULY	GM	3.236051	1.973000	0.008675	0.999866	0.000278
	EM	3.053247	1.992502	0.008663	0.999866	0.000278
	EPF	3.047172	1.858580	0.008076	0.999875	0.000259

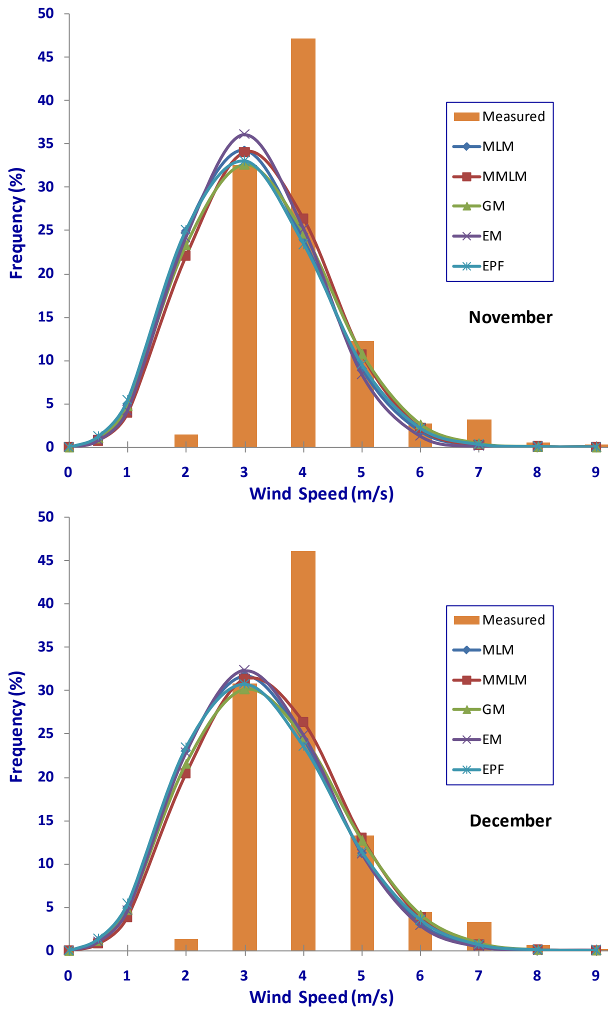

Fig. 8: Monthly Weibull distribution for the five models for November and December.

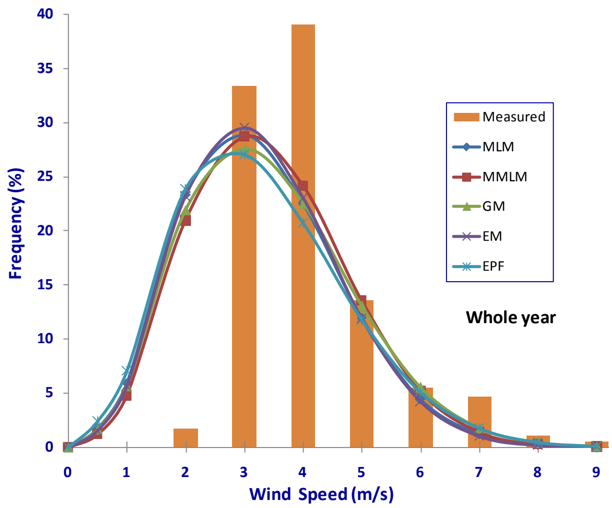

Fig. 9: Whole year Weibull distribution for the five models.

Table 11: Performance of the Weibull distribution methods for August

	Numerical methods	Weibull parameters		Statistical tests		
		Scale C	Shape k	RMSE	R^2	χ^2
	MLM	2.956144	2.054370	0.011571	0.999787	0.000394
	MMLM	3.114512	2.184705	0.012206	0.999775	0.000416
AUG	GM	3.119019	2.007000	0.011412	0.999790	0.000389
	EM	2.941456	2.037137	0.011482	0.999789	0.000391
	EPF	2.933920	1.848767	0.010519	0.999806	0.000358

Table 12: Performance of the Weibull distribution methods for September

	Numerical methods	Weibull parameters		Statistical tests		
		Scale C	Shape k	RMSE	R^2	χ^2
	MLM	2.977694	2.010530	0.013122	0.999747	0.000501
	MMLM	3.138731	2.139823	0.013795	0.999734	0.000526
SEPT	GM	3.151279	1.962000	0.012921	0.999751	0.000493
	EM	2.959907	1.979188	0.012948	0.999751	0.000494
	EPF	2.946215	1.753312	0.011627	0.999776	0.000444

Table 13: Performance of the Weibull distribution methods for October

	Numerical methods	Weibull parameters		Statistical tests		
		Scale C	Shape k	RMSE	R^2	χ^2
	MLM	2.860635	2.486673	0.015083	0.999541	0.000499
	MMLM	3.003020	2.626249	0.015633	0.999525	0.000517
OCT	GM	2.951801	2.451000	0.014933	0.999546	0.000494
	EM	2.860346	2.643559	0.015732	0.999522	0.000521
	EPF	2.868362	2.350742	0.014488	0.999559	0.000479

Table 14: Performance of the Weibull distribution methods for November

	Numerical methods	Weibull parameters		Statistical tests		
		Scale C	Shape k	RMSE	R^2	χ^2
NOV	MLM	2.937970	2.582118	0.013741	0.999597	0.000429
	MMLM	3.078318	2.719856	0.014276	0.999581	0.000446
	GM	3.051617	2.533900	0.013576	0.999602	0.000424
	EM	2.941858	2.760254	0.014424	0.999577	0.000451
	EPF	2.951412	2.479425	0.013331	0.999609	0.000416

Table 15: Performance of the Weibull distribution methods for December

	Numerical methods	Weibull parameters		Statistical tests		
		Scale C	Shape k	RMSE	R^2	χ^2
DEC	MLM	3.082174	2.470605	0.011732	0.999744	0.000349
	MMLM	3.224649	2.600235	0.012229	0.999733	0.000363
	GM	3.198297	2.429000	0.011628	0.999746	0.000345
	EM	3.079806	2.532571	0.011954	0.999739	0.000355
	EPF	3.084169	2.371493	0.011366	0.999752	0.000338

Table 16: Performance of the Weibull distribution methods for the whole year

	Numerical methods	Weibull parameters		Statistical tests		
		Scale C	Shape k	RMSE	R^2	χ^2
WHOLE YEAR	MLM	3.130414	2.222700	0.009999	0.999822	0.000316
	MMLM	3.280283	2.347260	0.010522	0.999813	0.000332
	GM	3.250418	2.187000	0.009918	0.999823	0.000313
	EM	3.125597	2.283603	0.010230	0.999818	0.000323
	EPF	3.122590	2.033948	0.009233	0.999836	0.000291

Table 17: Comparison between the wind speed standard deviation predicted by the methods and the measured data

	MLM		MMLM		GM		EM		EPF	
Period	**σ (m/s)**	**Error (%)**	**σ (m/s)**	**Error (%)**	**σ (m/s)**	**Error (%)**	**σ (m/s)**	**Error (%)**	**σ (m/s)**	**Error (%)**
Jan	1.371055	5.0211%	1.367865	4.7996%	1.451708	10.2979%	1.292620	-0.7421%	1.622144	19.7227%
Feb	1.486140	2.4037%	1.481457	2.0952%	1.594154	9.0165%	1.437930	-0.8685%	1.728116	16.0694%
Mar	1.388036	4.6202%	1.386756	4.5322%	1.463254	9.5232%	1.316087	-0.5941%	1.507001	12.1496%
Avril	1.244134	2.4538%	1.245241	2.5404%	1.297928	6.4967%	1.208223	-0.4456%	1.295383	6.3130%
May	1.509488	-2.3660%	1.502225	-2.8609%	1.625475	4.9384%	1.527612	-1.1515%	1.611840	4.1343%
June	1.500109	-2.0892%	1.493323	-2.5531%	1.609498	4.8493%	1.514397	-1.1260%	1.619788	5.4537%
July	1.410182	-1.7287%	1.404624	-2.1313%	1.517758	5.4816%	1.419104	-1.0892%	1.511020	5.0601%
Aug	1.336054	-1.3158%	1.331571	-1.6569%	1.440053	6.0011%	1.339669	-1.0424%	1.462144	7.4213%
Sept	1.372589	-1.9611%	1.367175	-2.3648%	1.485648	5.7983%	1.384239	-1.1029%	1.544458	9.3853%
Oct	1.090944	4.7950%	1.092230	4.9072%	1.139996	8.8916%	0.964379	-7.6996%	1.149110	9.6142%
Nov	1.084358	5.1893%	1.086306	5.3593%	1.144877	10.2011%	1.025074	-0.2940%	1.128431	8.8923%
Dec	1.182095	1.7061%	1.182982	1.7799%	1.244972	6.6705%	1.155980	-0.5144%	1.226047	5.2298%
Whole year	1.317905	0.2005%	1.315849	0.0447%	1.388370	5.2658%	1.275372	-3.1277%	1.424203	7.6492%

Table 18: Comparison between the wind speeds predicted by the methods and the measured data

	MLM		MMLM		GM		EM		EPF	
Period	**V (m/s)**	**Error (%)**	**V (m/s)**	**Error (%)**	**V (m/s)**	**Error (%)**	**V (m/s)**	**Error (%)**	**V (m/s)**	**Error (%)**
Jan	2.805208	-0.5625%	2.941153	4.0856%	2.923763	3.5151%	2.820988	0.0000%	2.820988	0.0000%
Feb	2.987524	-0.2800%	3.123752	4.0932%	3.142432	4.6633%	2.995890	0.0000%	2.995890	0.0000%
Mar	3.017099	-0.3280%	3.149393	3.8863%	3.133707	3.4053%	3.026996	0.0000%	3.026996	0.0000%
Avril	2.927431	0.0192%	3.056913	4.2541%	3.016847	2.9825%	2.926870	0.0000%	2.926870	0.0000%
May	2.850183	0.6123%	2.992154	5.3281%	3.008106	5.8301%	2.832730	0.0000%	2.832730	0.0000%
June	2.857329	0.5578%	2.998502	5.2396%	3.007790	5.5323%	2.841391	0.0000%	2.841391	0.0000%
July	2.720205	0.5037%	2.860729	5.3912%	2.869126	5.6680%	2.706503	0.0000%	2.706503	0.0000%
Aug	2.619188	0.4861%	2.758676	5.5179%	2.764438	5.7149%	2.606455	0.0000%	2.606455	0.0000%
Sept	2.639099	0.5677%	2.780155	5.6126%	2.794317	6.0910%	2.624117	0.0000%	2.624117	0.0000%
Oct	2.538184	-0.1601%	2.668507	4.7314%	2.618214	2.9014%	2.549748	0.0000%	2.542248	0.0000%
Nov	2.609384	-0.3512%	2.738572	4.3827%	2.708913	3.3358%	2.618549	0.0000%	2.618549	0.0000%
Dec	2.734338	0.0161%	2.864586	4.5621%	2.836318	3.6110%	2.733899	0.0000%	2.733899	0.0000%
Whole year	2.772922	-0.0047%	2.907272	4.6167%	2.879060	3.6820%	2.769469	0.0000%	2.767020	0.0000%

4. Discussions

4.1. Performance of the Weibull distribution methods

The proposed five Weibull PDF methods are effective in evaluating the parameters of the Weibull distribution for the available data. This fact is supported by the values of RMSE, Chi-square and R^2, which have magnitudes very close to each other. Obviously, the best parameters estimation reveals the lowest value of RMSE and chi-square, and the highest value of R^2. As a result, the EPF method showed the best accuracy even though the standard deviations gave the highest errors when comparing to the measured data standard deviations. Next, the MLM method ranked second followed by the GM method. The least precise methods are the MMLM method followed by the EM method.

4.2. Weibull scale and shape parameters

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 EPF method as the most accurate Weibull distribution model, it's observed that Weibull k values vary from 1.7533 in May to 2.4794 in November. It's noticed that for all the five Weibull PDF methods, k values are within typical Weibull k value for most wind conditions, ranging from 1.500 to 3.000 [19]. 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 EPF method, it's as well observed that Weibull C values vary from 2.8684 in October to 3.4172 in March. The scale C and shape k parameters determine the wind speed for optimum performance of a WECS as well as the speed range over which it's expected to operate at 10 meters height above ground level.

The predicted Weibull PDF parameters k and C permitted to calculate the mean wind speed and its standard deviation and the results are presented in tables 17 and 18. When considering the standard deviations analysis, it's observed that EPF method showed the highest errors followed by the GM and MLM methods. The EM method showed the smallest errors. The comparison between the mean wind speed predicted by the Weibull methods and the measured data showed that the EPF and EM methods presented 0.00% error while the MMLM and GM method showed greater errors, ranging from 3.8863% in March to 5.6126% in September for the MMLM and from 2.9014% in October to 6.0910% in September for the GM.

5. Conclusions

The performance assessment of five numerical methods for estimating Weibull distribution parameters for WECS in the district of Maroua in Cameroon has been the subject of this paper. The aim was to select the most accurate two-parameter Weibull PDF method for wind data as opposed to simply using the measured data in time-series or the frequency distribution of the measured data. The following main conclusions can be drawn from the present study:

1. The comparison between the mean wind speed predicted by the Weibull methods and the measured data, showed that the MMLM and the GM are the least effective methods to fit Weibull distribution curves for wind speed data;
2. The comparison between the standard deviation predicted by the Weibull methods and the measured data revealed that EPF method has the highest errors followed by the GM and MLM methods while the EM showed the smallest error ;
3. The studied Weibull methods are effective in evaluating the parameters of the Weibull distribution for the available data since the values of the RMSE, Chi-square and R^2 have magnitudes very close to each other ;
4. The results therefore, strongly recommend using as necessary the EPF method, as the more accurate estimation of the Weibull parameters in order to reduce uncertainties related to the wind energy output calculation.
5. The MLM method could be used as an alternative to the EPF method.

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