# COMPARISON OF FIVE NUMERICAL METHODS FOR ESTIMATING WEIBULL PARAMETERS FOR WIND ENERGY APPLICATIONS IN THE DISTRICT OF KOUSSERI, CAMEROON

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## ABSTRACT

*There is a crucial need in the Northern regions of Cameroon to enhance the development of wind technology and engineering, which can be considered to design and characterize Wind Energy Conversion Systems (WECS). The Weibull Probability Density Function (PDF) with two parameters is widely accepted and commonly utilized for modeling, characterizing and predicting wind resource and wind power, as well as assessing optimum performance of WECS. Therefore, it's crucial to precisely estimate the scale and shape parameters for any candidate site. The statistical data of 28 years (1985-2013) wind speed measurements in the district of Kousseri were analyzed and the Weibull parameters determined. The performance of the proposed five methods was carried out based on the correlation coefficient $R^2$ and root mean square error (RMSE). The results established that the proposed five methods are effective in evaluating the parameters of the Weibull distribution for the available data. However, the most accurate models are the energy pattern factor method followed by the maximum likelihood method and the graphical method. The least precise models are the modified maximum likelihood method and the empirical method.*

**Keywords:** Weibull distribution, Maximum likelihood method, modified maximum likelihood method, graphical method, energy pattern factor method.

## INTRODUCTION

The prospect of energy in Cameroon is challenging. With fast increasing energy demand, in addition to the growing depletion of natural resources and rising environmental consciousness, it has become crucial to enhance local energy supply with most promising renewable sources of energy. Wind, an inexhaustible resource, is a reliable renewable energy resource from a standpoint of long-term energy policy. Although wind energy is intermittent, wind turbine generators can effectively reduce environmental pollution, fossil fuel consumption, and the costs of overall electricity generation in the district of Kousseri. 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 PDF has been used to represent wind speed distributions for applications in wind loads studies [1]. In addition, the Weibull PDF has been


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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 [2].

In a study, Lysen [3] 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 [4] 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 [5-9]). 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, the maximum likelihood method, the modified maximum likelihood method, the energy pattern factor method, the graphical method, and the empirical method are explored and their suitability compared for the district of Kousseri 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).

## MATERIALS AND METHODS

### 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 and standard deviation of the measured data while the monthly wind speed frequencies distributions are described by the figure 1.

**Table 1. Geographical coordinates of the study area**

| *Variable* | *Value* |
|---|---|
| Latitude | 12°04’60” N |
| Longitude | 15°01’59”E |
| Anemometer Height | 10 meters height above ground level |
| Elevation | 302 meters above sea level |


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**Table 2. Mean wind speed and wind speed standard deviation**

| *Month* | *Mean Wind Speed* $\bar{V}$ *(m/s)* | *Standard Deviation σ (m/s)* |
|---|---|---|
| Jan. | 3.61 | 1.17 |
| Feb. | 4.11 | 1.31 |
| Mar. | 4.23 | 1.18 |
| April | 3.79 | 1.33 |
| May | 3.77 | 1.28 |
| June | 4.00 | 1.41 |
| July | 3.69 | 1.39 |
| Aug. | 3.24 | 1.44 |
| Sept. | 3.20 | 1.51 |
| Oct. | 3.14 | 1.20 |
| Nov. | 3.50 | 1.16 |
| Dec. | 3.48 | 1.09 |
| Avg. | 3.65 | 1.28 |

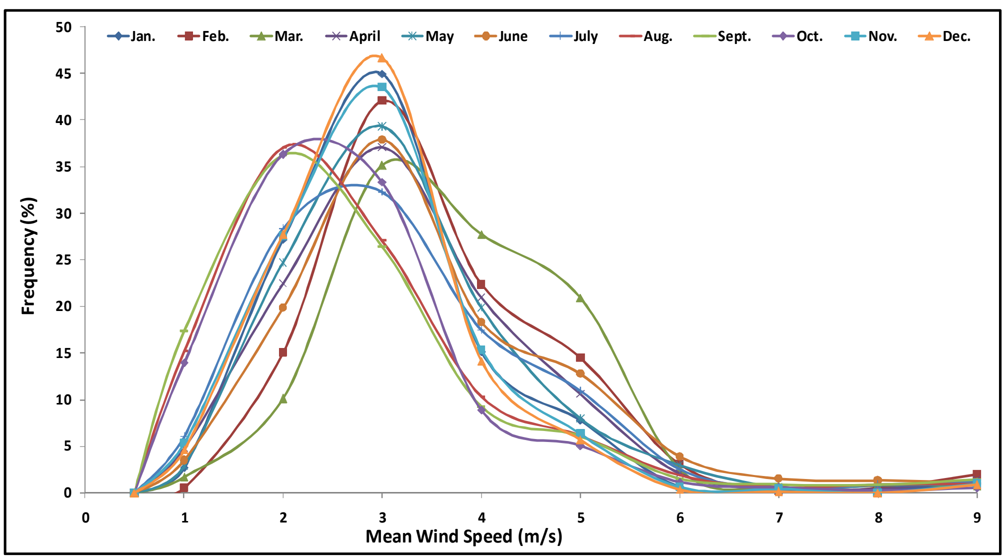


Figure 1. Frequency distribution of measured monthly wind speed

## Methods to Estimate Weibull Parameters

The daily, monthly, seasonal, and yearly wind speed probability density distributions are modeled using the Weibull PDF. The Weibull PDF can be used with acceptable accuracy for prediction of wind energy output required for preliminary design and assessment of wind power plants [10]. 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][11][14-15] :

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

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:

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

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

### *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, 14-15]. The logarithmic transformation is the foundation of this method. By converting the equation (2) into logarithmic form, the following equation is obtained:

$$\ln\left[-\ln\left(1 - F(V)\right)\right] = kln(V) - kln(C) \ldots\ldots\ldots (3)$$

The Weibull shape and scale parameters are estimated by plotting $ln(V)$ against $\ln\left[-\ln\left(1 - F(V)\right)\right]$ 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 $-kln(C)$.

### *Maximum Likelihood method*

The Maximum Likelihood Estimation method (MLE) is a mathematical expression known as a likelihood function of the wind speed data in time series format. The MLE method was used by Deligiorgi*et al* [8] and Costa Rocha *et al*[6], quoting Stevens and Smulders [11] in their study for the estimation of parameters of the Weibull wind speed distribution for wind energy utilization purposes. The MLE 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:

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

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

Where: $n$ = number of non zero data values

$i$ = measurement interval


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

***Modified Maximum Likelihood Method***

The Modified Maximum Likelihood Estimation method (MMLE) is used only for wind speed data available in the Weibull distribution format. The MMLE 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]:

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

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

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

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

***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 $[m/s]$

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

***Energy pattern factor method***

The energy pattern factor method (EPFM) is related to the averaged data of wind speed and is defined by the following equations [6][16]:

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

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

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

The standard deviation $\sigma$ of the observed data is determined using the following equation [11-12]:

$$\sigma = C[\Gamma(1 + 2/k) - \Gamma^2(1 + 1/k)]^{1/2} \quad (13)$$

Where the standard gamma function is given by:

$$\Gamma(x) = \int_0^\infty t^{x-1} \exp(-t)\, dt \quad (14)$$

The gamma function used by J.F. Manwell*et al.* [13] quoting Jamil [12] is given by:

$$\Gamma(x) = \left(\sqrt{2\pi x}\right)(x^{x-1})(e^{-x})\left(1 + \frac{1}{12x} + \frac{1}{288x^2} - \frac{139}{51840x^3} + \cdots\right) \quad (15)$$

The Weibull scale parameters $C$ can be determined using the equation (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 [16-17]:

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2\right]^{1/2} \quad (16)$$

$$R^2 = \frac{\sum_{i=1}^{N}(y_i-z_i)^2-\sum_{i=1}^{N}(y_i-x_i)^2}{\sum_{i=1}^{N}(y_i-z_i)^2} \quad (17)$$

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;

## RESULTS

The mean wind speeds as well as the standard deviation for each of the five numerical methods considered in the analysis are presented in the table 2. The Figures 2 and 3 show the Weibull distribution functions, describing the wind speed frequency against the mean wind speed for the actual data on a monthly basis from 1985 to 2013 in the district of Kousseri, Cameroon. In the aforementioned figures, the five numerical methods are plotted alongside the measured wind speed frequencies. Subsequently, the tables 3 to 14 show the performance of the Weibull distribution models for each month. The table 15 summarizes the performance of the Weibull distribution models for the yearly average. Lastly, Table 16 presents the relative error for the comparison between the wind speed standard deviation predicted by the methods and the measured data. It is important to note that the standard deviation of the measured data is the same as the one obtained using the empirical method since it is the same formula that has been utilized for both.

**Table 2. Mean wind speed and wind speed standard deviation**

| *Month* | *MLM* | *MMLM* | *GM* | *EM* | *EPFM* | *Mean Wind Speed* |
|---|---|---|---|---|---|---|
| | $\sigma$ | $\sigma$ | $\sigma$ | $\sigma$ | $\sigma$ | $\bar{V}$ |
| Jan. | 1.32 | 1.32 | 1.35 | 1.17 | 1.36 | 3.61 |
| Feb. | 1.46 | 1.47 | 1.51 | 1.31 | 1.52 | 4.11 |
| Mar. | 1.31 | 1.31 | 1.34 | 1.18 | 1.41 | 4.23 |
| April | 1.43 | 1.44 | 1.45 | 1.33 | 1.49 | 3.79 |
| May | 1.39 | 1.40 | 1.42 | 1.28 | 1.45 | 3.77 |
| June | 1.50 | 1.50 | 1.55 | 1.41 | 1.56 | 4.00 |
| July | 1.46 | 1.47 | 1.51 | 1.39 | 1.52 | 3.69 |
| Aug. | 1.48 | 1.48 | 1.54 | 1.44 | 1.57 | 3.24 |
| Sept. | 1.54 | 1.53 | 1.62 | 1.51 | 1.66 | 3.20 |
| Oct. | 1.27 | 1.28 | 1.33 | 1.20 | 1.33 | 3.14 |
| Nov. | 1.29 | 1.29 | 1.33 | 1.16 | 1.33 | 3.50 |
| Dec. | 1.23 | 1.24 | 1.28 | 1.09 | 1.27 | 3.48 |
| Avg. | 1.38 | 1.39 | 1.43 | 1.28 | 1.45 | 3.65 |



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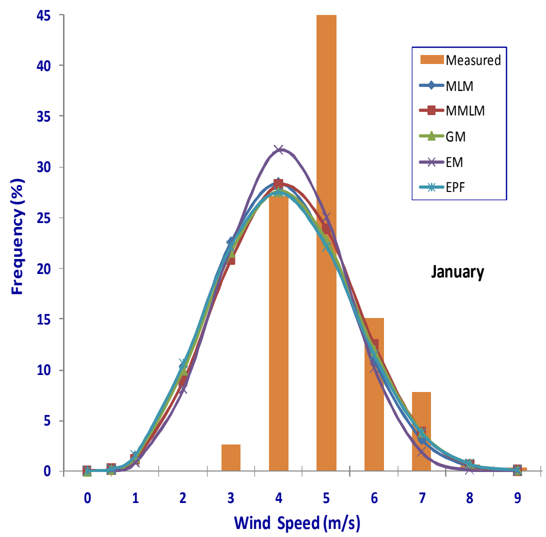


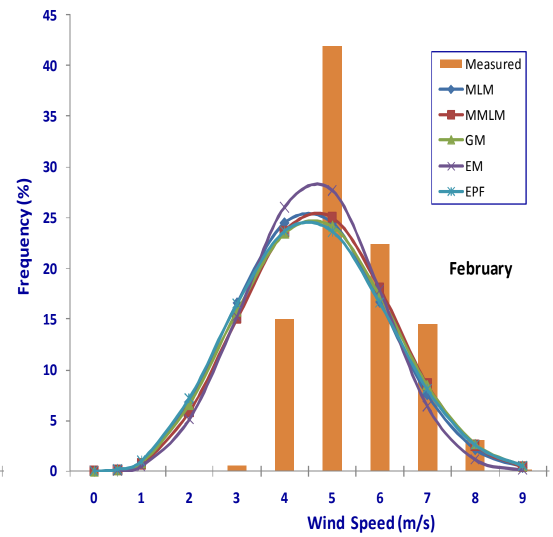


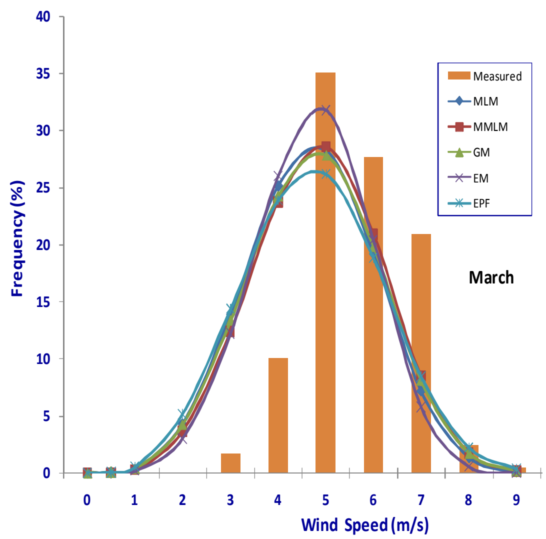


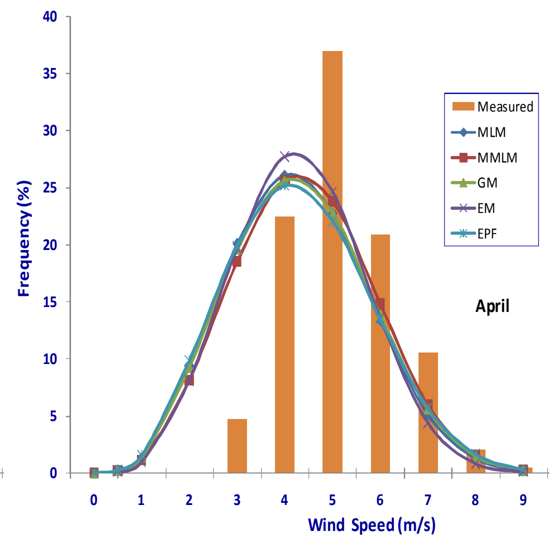


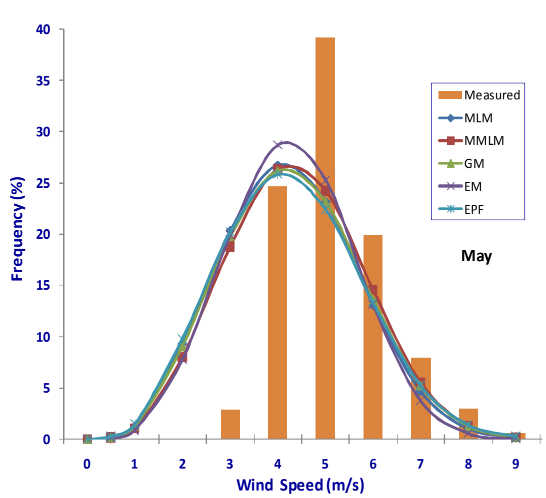


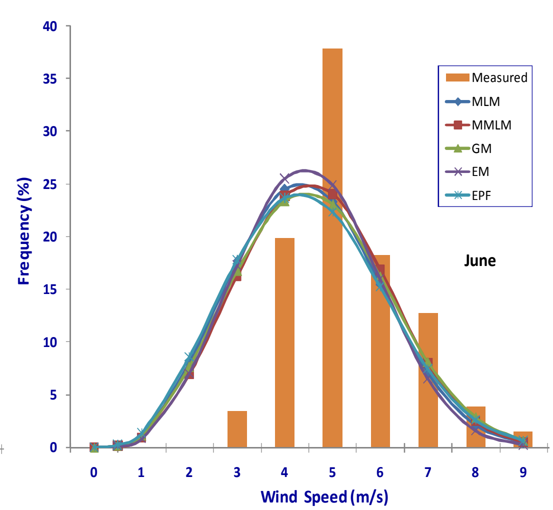


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Figure 2. Weibull distribution functions for the five numerical methods from January to June

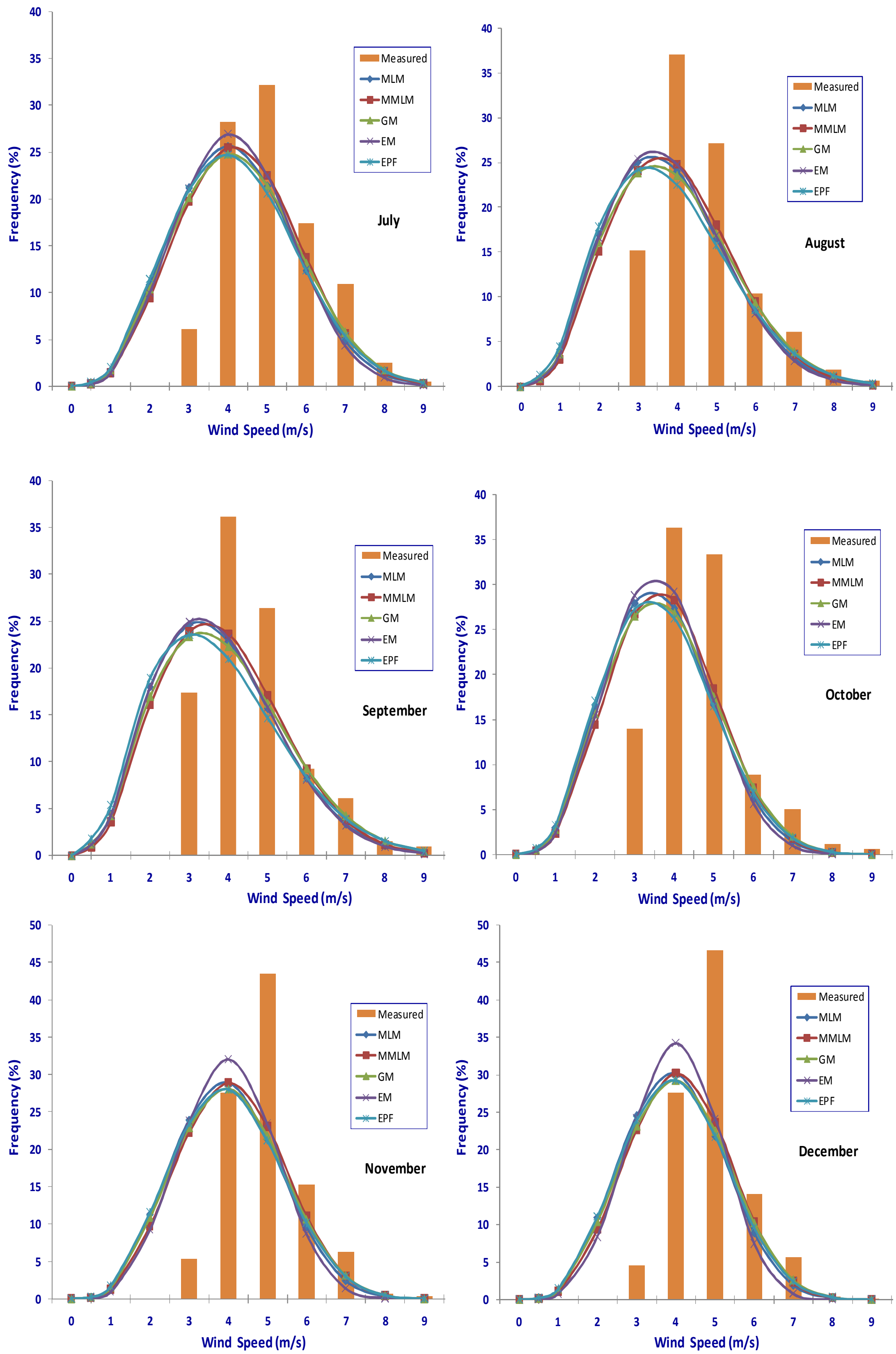



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Figure 3. Weibull distribution functions for the five numerical methods from July to December

**Table 3. Performance of the Weibull distribution models for the month of January**

| *Month* | *Numerical Methods* | *Weibull Parameters* | | *Statistical Tests* | |
|---|---|---|---|---|---|
| | | *Scale C* | *Shape K* | *RMSE* | *$R^2$* |
| January | Maximum Likelihood | 4.009 | 2.959 | 0.17149 | 0.99761 |
| | Modified Maximum Likelihood | 4.144 | 3.067 | 0.17708 | 0.99745 |
| | Graphical | 4.090 | 2.932 | 0.17217 | 0.99759 |
| | Empirical | 4.014 | 3.389 | 0.18367 | 0.99726 |
| | Energy Pattern Factor | 4.044 | 2.876 | 0.16961 | 0.99766 |

**Table 4. Performance of the Weibull distribution models for the month of February**

| *Month* | *Numerical Methods* | *Weibull Parameters* | | *Statistical Tests* | |
|---|---|---|---|---|---|
| | | *Scale C* | *Shape K* | *RMSE* | *$R^2$* |
| February | Maximum Likelihood | 4.564 | 3.041 | 0.18220 | 0.99793 |
| | Modified Maximum Likelihood | 4.699 | 3.138 | 0.18620 | 0.99784 |
| | Graphical | 4.665 | 3.011 | 0.18249 | 0.99793 |
| | Empirical | 4.566 | 3.456 | 0.19271 | 0.99769 |
| | Energy Pattern Factor | 4.602 | 2.935 | 0.17970 | 0.99799 |

**Table 5. Performance of the Weibull distribution models for the month of March**

| *Month* | *Numerical Methods* | *Weibull Parameters* | | *Statistical Tests* | |
|---|---|---|---|---|---|
| | | *Scale C* | *Shape K* | *RMSE* | *$R^2$* |
| March | Maximum Likelihood | 4.667 | 3.561 | 0.19601 | 0.99775 |
| | Modified Maximum Likelihood | 4.798 | 3.665 | 0.19927 | 0.99768 |
| | Graphical | 4.738 | 3.535 | 0.19602 | 0.99775 |
| | Empirical | 4.668 | 4.039 | 0.20588 | 0.99752 |
| | Energy Pattern Factor | 4.720 | 3.298 | 0.19039 | 0.99788 |

**Table 6. Performance of the Weibull distribution models for the month of April**

| *Month* | *Numerical Methods* | *Weibull Parameters* | | *Statistical Tests* | |
|---|---|---|---|---|---|
| | | *Scale C* | *Shape K* | *RMSE* | *$R^2$* |
| April | Maximum Likelihood | 4.237 | 2.859 | 0.17245 | 0.99782 |
| | Modified Maximum Likelihood | 4.373 | 2.960 | 0.17748 | 0.99769 |
| | Graphical | 4.283 | 2.846 | 0.17280 | 0.99781 |
| | Empirical | 4.239 | 3.114 | 0.17991 | 0.99763 |
| | Energy Pattern Factor | 4.261 | 2.753 | 0.16958 | 0.99789 |

**Table 7. Performance of the Weibull distribution models for the month of May**

| *Month* | *Numerical Methods* | *Weibull Parameters* | | *Statistical Tests* | |
|---|---|---|---|---|---|
| | | *Scale C* | *Shape K* | *RMSE* | *$R^2$* |
| May | Maximum Likelihood | 4.203 | 2.923 | 0.17384 | 0.99776 |
| | Modified Maximum Likelihood | 4.338 | 3.026 | 0.17888 | 0.99762 |
| | Graphical | 4.261 | 2.906 | 0.17425 | 0.99774 |
| | Empirical | 4.203 | 3.222 | 0.18230 | 0.99753 |
| | Energy Pattern Factor | 4.229 | 2.812 | 0.17089 | 0.99783 |

**Table 8. Performance of the Weibull distribution models for the month of June**

| *Month* | *Numerical Methods* | *Weibull Parameters* | | *Statistical Tests* | |
|---|---|---|---|---|---|
| | | *Scale C* | *Shape K* | *RMSE* | *$R^2$* |
| June | Maximum Likelihood | 4.472 | 2.892 | 0.17687 | 0.99794 |
| | Modified Maximum Likelihood | 4.607 | 2.988 | 0.18125 | 0.99784 |
| | Graphical | 4.592 | 2.857 | 0.17735 | 0.99793 |
| | Empirical | 4.469 | 3.091 | 0.18241 | 0.99781 |
| | Energy Pattern Factor | 4.490 | 2.764 | 0.17331 | 0.99802 |



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**Table 9. Performance of the Weibull distribution models for the month of July**

| *Month* | *Numerical Methods* | *Weibull Parameters* | | *Statistical Tests* | |
|---|---|---|---|---|---|
| | | *Scale C* | *Shape K* | *RMSE* | $R^2$ |
| July | Maximum Likelihood | 4.138 | 2.712 | 0.16619 | 0.99786 |
| | Modified Maximum Likelihood | 4.276 | 2.813 | 0.17168 | 0.99771 |
| | Graphical | 4.242 | 2.683 | 0.16704 | 0.99784 |
| | Empirical | 4.137 | 2.878 | 0.17136 | 0.99772 |
| | Energy Pattern Factor | 4.152 | 2.601 | 0.16279 | 0.99795 |

**Table 10. Performance of the Weibull distribution models for the month of August**

| *Month* | *Numerical Methods* | *Weibull Parameters* | | *Statistical Tests* | |
|---|---|---|---|---|---|
| | | *Scale C* | *Shape K* | *RMSE* | $R^2$ |
| August | Maximum Likelihood | 3.656 | 2.329 | 0.14214 | 0.99795 |
| | Modified Maximum Likelihood | 3.802 | 2.437 | 0.14975 | 0.99773 |
| | Graphical | 3.776 | 2.297 | 0.14405 | 0.99789 |
| | Empirical | 3.650 | 2.400 | 0.14456 | 0.99788 |
| | Energy Pattern Factor | 3.654 | 2.173 | 0.13630 | 0.99812 |

**Table 11. Performance of the Weibull distribution models for the month of September**

| *Month* | *Numerical Methods* | *Weibull Parameters* | | *Statistical Tests* | |
|---|---|---|---|---|---|
| | | *Scale C* | *Shape K* | *RMSE* | $R^2$ |
| September | Maximum Likelihood | 3.618 | 2.202 | 0.13641 | 0.99806 |
| | Modified Maximum Likelihood | 3.768 | 2.310 | 0.14433 | 0.99783 |
| | Graphical | 3.762 | 2.166 | 0.13884 | 0.99799 |
| | Empirical | 3.608 | 2.234 | 0.13736 | 0.99804 |
| | Energy Pattern Factor | 3.606 | 2.016 | 0.12915 | 0.99826 |

**Table 12. Performance of the Weibull distribution models for the month of October**

| *Month* | *Numerical Methods* | *Weibull Parameters* | | *Statistical Tests* | |
|---|---|---|---|---|---|
| | | *Scale C* | *Shape K* | *RMSE* | *$R^2$* |
| October | Maximum Likelihood | 3.521 | 2.644 | 0.14959 | 0.99758 |
| | Modified Maximum Likelihood | 3.660 | 2.760 | 0.15736 | 0.99732 |
| | Graphical | 3.628 | 2.608 | 0.15136 | 0.99752 |
| | Empirical | 3.521 | 2.830 | 0.15589 | 0.99737 |
| | Energy Pattern Factor | 3.534 | 2.533 | 0.14609 | 0.99769 |

**Table 13. Performance of the Weibull distribution models for the month of November**

| *Month* | *Numerical Methods* | *Weibull Parameters* | | *Statistical Tests* | |
|---|---|---|---|---|---|
| | | *Scale C* | *Shape K* | *RMSE* | *$R^2$* |
| November | Maximum Likelihood | 3.896 | 2.934 | 0.16844 | 0.99755 |
| | Modified Maximum Likelihood | 4.031 | 3.044 | 0.17444 | 0.99737 |
| | Graphical | 3.982 | 2.904 | 0.16930 | 0.99753 |
| | Empirical | 3.902 | 3.316 | 0.17965 | 0.99721 |
| | Energy Pattern Factor | 3.928 | 2.849 | 0.16650 | 0.99761 |

**Table 14. Performance of the Weibull distribution models for the month of December**

| *Month* | *Numerical Methods* | *Weibull Parameters* | | *Statistical Tests* | |
|---|---|---|---|---|---|
| | | *Scale C* | *Shape K* | *RMSE* | *$R^2$* |
| December | Maximum Likelihood | 3.860 | 3.059 | 0.17149 | 0.99743 |
| | Modified Maximum Likelihood | 3.994 | 3.174 | 0.17746 | 0.99725 |
| | Graphical | 3.960 | 3.022 | 0.17243 | 0.99741 |
| | Empirical | 3.867 | 3.548 | 0.18510 | 0.99701 |
| | Energy Pattern Factor | 3.900 | 2.981 | 0.16997 | 0.99748 |



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**Table 15. Performance of the Weibull distribution models for the yearly average**

| *Month* | *Numerical Methods* | *Weibull Parameters* | | *Statistical Tests* | |
|---|---|---|---|---|---|
| | | *Scale C* | *Shape K* | *RMSE* | $R^2$ |
| *Yearly Average* | Maximum Likelihood | 4.070 | 2.843 | 0.16907 | 0.99773 |
| | Modified Maximum Likelihood | 4.207 | 2.949 | 0.17467 | 0.99758 |
| | Graphical | 4.165 | 2.814 | 0.16988 | 0.99771 |
| | Empirical | 4.070 | 3.126 | 0.17750 | 0.99750 |
| | Energy Pattern Factor | 4.093 | 2.716 | 0.16548 | 0.99782 |

**Table 16. Comparison between the wind speed standard deviation predicted by the methods and the measured data**

| *Months* | *MLE* | *MMLE* | *GM* | *EM* | *EPFM* |
|---|---|---|---|---|---|
| *January* | -12.10% | -12.38% | -15.27% | 0.00% | -15.89% |
| *February* | -11.44% | -11.69% | -14.85% | 0.00% | -15.80% |
| *March* | -11.24% | -11.60% | -13.62% | 0.00% | -20.04% |
| *April* | -7.53% | -7.73% | -9.11% | 0.00% | -11.68% |
| *May* | -8.62% | -8.85% | -10.66% | 0.00% | -12.96% |
| *June* | -5.89% | -6.09% | -9.88% | 0.00% | -10.52% |
| *July* | -5.24% | -5.39% | -8.90% | 0.00% | -9.47% |
| *August* | -2.84% | -2.76% | -7.50% | 0.00% | -9.30% |
| *September* | -1.60% | -1.38% | -7.21% | 0.00% | -9.69% |
| *October* | -6.01% | -6.17% | -10.55% | 0.00% | -10.44% |
| *November* | -10.81% | -11.09% | -14.26% | 0.00% | -14.56% |
| *December* | -13.21% | -13.55% | -17.37% | 0.00% | -16.94% |
| *Average* | -8.44% | -8.66% | -11.95% | 0.00% | -13.42% |

## DISCUSSIONS

### Performance of the Weibull Distribution Models

The performance of the proposed five models was carried out based on the correlation coefficient $\mathbf{R^2}$ and root mean square error (RMSE). Therefore, the best parameters estimation shall contain to the lowest value of RMSE and the highest value of $R^2$. The results established that the proposed five methods are effective in evaluating the parameters of the Weibull distribution for the available data. However, the most accurate models are the energy pattern factor method followed by the maximum likelihood method and the graphical method. The least precise models are the modified maximum likelihood method and the empirical method. Moreover, it is further observed that the values of RMSE, and $R^2$, have magnitudes very close to each other for all the numerical methods used for the data collected in the district of Kousseri, Cameroon.

### 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. Our study showed k values ranging from 2.02 to 4.04. Typical Weibull k valuefor most wind conditions ranges from 1.5 to 3 [18]. 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. Our analysis showed C values ranging from 3.521 to 4.798 for the mean wind speed in the district of Kousseri. 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.The comparison between the wind speed standard deviation predicted by the models and the measured data showed a greater relative error of -13.42% on average for the energy Pattern Factor method while the smaller relative error was -8.44 using the maximum likelihood method.

## CONCLUSION

The aim of this work was to provide useful insights to engineers when selecting a method that gives more accurate estimation for the Weibull parameters in the district of Kousseri 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 data collected in the district of Kousseri, Cameroon;
3. 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;
4. The comparison of the proposed methods established that the most accurate models are the energy pattern factor method followed by the maximum likelihood method and the graphical method. The least precise models are the modified maximum


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likelihood method and the empirical method. The results therefore, strongly suggest that the energy pattern factor method and the maximum likelihood method may be more reliable in estimating Weibull shape and scale parameters for the district of Kousseri, However, extension of this study to other locations in the Northern region of Cameroon and over a similar study periods is required for a sound conclusion.

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