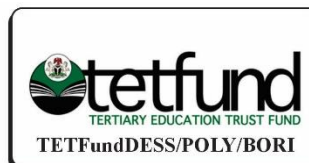


## COMPARATIVE ANALYSIS OF ESTIMATION METHOD FOR THE PARAMETERS OF WEIBULL DISTRIBUTION USING A MULTI- CRITERIA DECISION ALGORITHM



Zukbee, N.A.<sup>1</sup>, Diemuodeke, E.O.<sup>2</sup> & Nkoi, B.<sup>3</sup>

1. Department of Mechanical Engineering, Kenule Beeson Saro-Wiwa Polytechnic Bori
2. Department of Mechanical Engineering, University of Port Harcourt
3. Department of Mechanical Engineering, Rivers State University

### ABSTRACT:

*Most studies use the Weibull 2-parameter distribution to determine energy potential in some sites in the Niger Delta region of Nigeria. However, it is well known that parameter estimates have significant effect on the success of Weibull distribution to wind energy application. The accuracy of result obtained is based on the suitability of the method of determining the Weibull constant. Considering the need for the most accurate estimation, sixteen years (2001 to 2016) wind speed data obtained from Nigerian Meteorological Agency (NIMET) were fitted to two parameters Weibull distribution functions for selected location in the Niger Delta region of Nigeria. The data was statistically analyzed using MLM, MOM and PDM methods. The three methods applied here were further compared among themselves according to various goodness of fit criteria which include RMSE, KS, PDE, and R<sup>2</sup> and subsequently subjected to a multi-criteria decision analysis based on the technique for order of preference by similarity to ideal solution (TOPSIS) to decide the best alternative. From the TOPSIS investigation, the PDM method proved to be the best option for estimating the parameters of the Weibull distribution at 0.962, 0.967, and 1.00 respectively for Calabar, Port Harcourt, and Yenegoa.*

**Keywords:** Comparative, Estimation, Wind Speed, TOPSIS Analysis, Weibull Constant.

## 1. Introduction

Numerous wind resource assessment studies have been carried out globally to analyze the potential of local areas for the production of energy from wind power. From the 1970s, data regarding wind energy resources have been collected from various sites, leading to the installation of several wind farms particularly in Canada, Denmark, Netherlands, Sweden, UK, U.S.A, Germany, and India (Rao & Parulekar, 2004).

Despite the enormous potential, no country in West Africa has yet used wind energy to power the system. According to Ajayi et al. (2014), one of the main obstacles to the development of wind projects in West Africa may be related to the region's incorrect wind classification or improper evaluation studies. The Solar and Wind Energy Resource Assessment (SWERA) project was launched by the United Nations Environment Program in 2002 with financial support from the Global Environment Facility to carry out initial mapping using only satellite-based data in recognition of the lack of information on the potential for wind (and solar) resource in underdeveloped countries (UNDP, 2015).

With the aim of creating high quality mapping outputs (and associated datasets) that are validated with specially commissioned ground-based data, the Energy Sector Management Assistance Program (ESMAP), a program within the World Bank, recently launched an initiative to map wind and other renewable energy resources in a number of developing countries. The International Renewable Energy Agency (IRENA) is also working to compile publicly accessible GIS data on wind and other renewable energy resources into a Global Atlas for Renewable Energy.

Dike et al. (2011) performed wind assessment analysis for three Niger Delta States with wind speed data obtained from US National Aeronautics and Space Administration (NASA), using the two-parameter Weibull distribution. The study obtained a mean wind velocity ranging from 2.1 to 3.0 m/s for the cities, suggesting that the sites are low wind speed region.

Izelu et al. (2013) used the Ralieggh probability distribution function to determine wind velocity and energy utilization in the Choba banks of the Calabar River in Port Harcourt, Rivers State, Nigeria. The result obtained was an average wind velocity of 17.75m/s at an altitude of 50m. The result also specified that the selected site has high potential for wind energy utilization.

Uquetan et al. (2015) focused on wind energy potential in Calabar, a coastal city in

the Niger Delta region of Nigeria. The result showed that the annual wind speed is 1.3m/s indicating Calabar as a low wind speed region.

Akintomide et al. (2017) employed the Weibull two parameter probability density function in carrying out assessment of the wind energy potential of Koluama, Bayelsa State, South-South Nigeria. The result revealed a seasonal wind speed ranging from 4.05m/s to 4.32m/s and wind power density of 82W/m<sup>2</sup>. However, the capacity factor was relatively low (<10%) and this raises concern about economic viability of large scale wind power project in the study site.

Kasra and Ali (2013) in an attempt to find better method for calculating wind power used Weibull distribution based on two methods; standard deviation method and power density method. Statistical comparison showed more accuracy of the power density method.

Although various wind resource assessment studies have been carried out in the Niger Delta region of Nigeria, there has not been any concord as to which estimation method works best for each location. The method used in evaluating Weibull constant has effect on the result obtained (Ilham, 2016).

Kasra and Ali (2013) in an attempt to find better method for calculating wind power used Weibull distribution based on two methods; standard deviation method and power density method. Statistical comparison showed more accuracy of the power density method.

In this study, three mostly used methods MLM, MOM, and PDM are adapted to three cities in the Niger Delta region of Nigeria (Calabar, Port Harcourt, and Yenegoa). To know which estimation method works best and in which circumstance, data is simulated from Weibull distribution to know the true value of the shape and scale parameters and then statistical comparison according to the various goodness of fit criteria and subsequently subjected to a multi-criteria decision analysis.

According to Gugliani et al. (2018), simulating data from a Weibull distribution to determine the actual values of the shape and scale parameters, followed by using statistical comparison to determine which estimation method performs best under which conditions, is the best way to determine which estimation method performs best overall. The relative percentage error (RPE), mean percentage error (MPE), mean absolute percentage error (MAPE), and coefficient of determination were some of the statistical metrics employed in the investigation. The percentage difference between the computed values from the Weibull distribution and the calculated value from the measured data was displayed by RPE. MPE and MAPE

displayed the absolute average of percentage deviation of RPE and the average of percentage deviation of RPE, respectively. When these numbers are near to zero, the best outcomes are produced. The optimal value is one (Ilhan 2016).

## 2.0 Materials and Methods

### 2.1 Study Area

The Niger Delta region of Nigeria is the study area. The Niger Delta is the region of the Niger River that borders the Gulf of Guinea. Within the broader Gulf of Guinea, the Niger Delta divides the Bight of Benin from the Bight of Bonny. The largest area of wetlands in all of Africa is found in the Niger Delta region, which makes up about 8% of all of Nigeria. It is located in Nigeria's South-South region. It is the country's economic center and home to over 31 million people from over 40 different ethnic groups (Hogan, 2013).

### 2.2 Data Source

Data for this analysis was obtained from the Nigerian Meteorological (NIMET) Agency from sixteen years recordings (2001-2016).

## 2.3 Mathematical Formulations

### 2.3.1 Wind Speed Analysis

The Weibull distribution can be expressed as a probability density function,  $f(v)$ , and a cumulative distribution function,  $F(v)$ , given as follows:

$$f_p(v) = \frac{k}{c} \left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^k} \quad (1)$$

The Weibull's cumulative distribution function can be expressed as follows:

$$F_p(v) = 1 - e^{-\left(\frac{v}{c}\right)^k} \quad (2)$$

### 2.3.2 Estimating the Parameters $k$ and $c$ of Weibull Distribution

1. The Maximum Likelihood Method – MLM for obtaining  $k$  and  $c$   
 This method is performed in two stages: In the first stage the shape parameter  $k$  is estimated using the following Equation iteratively (Steven *et al*, 1979; Chang 2011)

$$k = \left[ \frac{\sum_{i=1}^n v_i^k \ln(v_i)}{\sum_{i=1}^n v_i^k} - \frac{\sum_{i=1}^n \ln(v_i)}{n} \right]^{-1} \quad (3)$$

where  $v_i$  is the observed wind speed data and  $n$  is the number of all observed non – zero wind speed data. After obtaining the value of shape parameter  $k$ , at the second stage, the scale parameter  $c$  is estimated from the following Equation:

$$c = \left( \frac{1}{n} \sum_{i=1}^n v_i^k \right)^{\frac{1}{k}} \quad (4)$$

2. The Moment Method – MOM for obtaining k and c

Weibull parameters are obtained through this method by equating population moment to corresponding sample moments as follows (Justus *et al*, 1975; Azad *et al*, 2014).

$$\bar{v} = c \sqrt{\left(1 + \frac{1}{k}\right)} \quad (5)$$

$$S = c \left[ \Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right) \right]^{\frac{1}{2}} \quad (6)$$

Where  $\bar{v}$  and S are the sample mean and standard deviation of wind speed calculated respectively as follows:

$$\bar{v} = \frac{1}{n} \sum_{i=1}^n V_i \quad (7)$$

$$S = \left[ \frac{1}{n} \sum_{i=1}^n (V_i - \bar{V})^2 \right]^{\frac{1}{2}} \quad (8)$$

And also  $\Gamma(\cdot)$  is the gamma function defined by

$$\Gamma(a) = \int_0^{\infty} x^{a-1} e^{-x} dx \quad (9)$$

3. The probability weighted moments based on the power density method – PWMBP for obtaining k and c (Usta, 2013).

The PWMs of a random variable x with a cumulative density function, F(x), are defined as follows:

$$PWM_{i,r,s} = E [x^i (F(x))^r (1 - F(x))^s] \quad (10)$$

where i, r, s are real numbers.

Based on the form considered, Equation (3.8) can be resolved into the following form (Tar, 2008).

$$PWM_{i0s} = E [x (1 - F(x))^s] \quad (11)$$

OR

By equalizing the sample PWMs with the population PWMs (Hosking, 1990; Usta, 2013).

$$PWM_{1,0,5} = \frac{c \Gamma\left(1 + \frac{1}{k}\right)}{(1+s)^{1+\frac{1}{k}}} \quad (12)$$

where  $s$  is a positive integer value

Equating the calculated sample PWMs and the population PWMs, and making the necessary arrangements, gives

$$k = \frac{\ln(2)}{\ln(\bar{c})} \quad (13)$$

where  $\bar{c}$  is given by

$$\bar{c} = \frac{\bar{v}}{\frac{1}{n(n-1)} \sum_{i=1}^n v_i(n-1)} \quad (14)$$

where  $v(\bar{i})$  is  $i$ th ascending ordered wind speed data.

On the other hand, it is well known that the mean power density (per unit of rotor swept area  $A$ ) based on Weibull distribution ( $P_{WD}$ ) and the mean power density of the time series wind data ( $P_{REF}$ ) are obtained, respectively, as follows (Kantar 2015; Akdag 2009; Celik 2007).

$$P_{WD} = \frac{1}{2} \rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \quad (15)$$

$$P_{REF} = \frac{1}{2} \rho \sum_{i=1}^n \frac{v_i^3}{n} \quad (16)$$

The performance selection criteria of the distributions.

To determine the performance of the three methods used in estimating the parameters of Weibull distribution, the  $R^2$ , RMSE, KS statistic and PDE are used. The formulae of the mentioned performance selection criteria are as follows:

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

where  $R^2$  is the coefficient of determination,  $N$  is the total number of bins,  $y_{ij}$ th the observed

probability of wind speed data,  $x_{ij}$ th the predicted probability calculated from Weibull distribution,  $\bar{y}$  is the average of  $y_i$  values.

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

where RMSE is the root mean square error,

$$KS = \max_v |F_n(v) - F(v)| \quad (19)$$

KS is the Kolmogorov – Smiirnov distance, KS is the Kolmogorov – Smiirnov distance,

$$KS = \max_v |F_n(v) - F(v)| \quad (19)$$

$$PDE(\%) = \left| \frac{P_{REF} - P_{WD}}{P_{REF}} \right| \times 100 \quad (20)$$

PDE is the power density error (w),  $P_{REF}$  is the mean power density of the time series data and  $P_{WD}$  is the calculated wind power based on Weibull distribution. The best method for estimating Weibull parameters for the actual data is determined according to the highest value of  $R^2$  and the lowest values of RMSE, KS and PDE (Usta, *et al*, 2012; Kantar *et al* 2015).

To deploy the TOPSIS method, the following algorithm applies (Diemuodeke *et al*, 2016; Diemuodeke *et al*, 2018).

Step 1: Specify the criteria (m) and the alternatives (n)  $i = 1, 2, 3, \dots, m$  and  $j = 1, 2, 3, \dots, n$  Criteria come in: positive criteria (i.e. more is better) or negative criteria (i.e. less is better).

Step 2: Construct the decision matrix, X, and the weight of criteria, W, Let  $X = \{x_{ij}\}$ , be the decision matrix and  $W = [w_i]$  a weight vector, where  $\sum_{i=1}^m w_i = 1$ ; and  $x_{ij}$  is the element of the decision matrix that resides in the i-th column and j-th row.

Step 3: Obtain the normalized matrix R.

This is done by applying the equation

$$R = \{(r_{ij})\} \equiv \frac{x_{ij}}{(\sum_{i=1}^m x_{ij}^2)^{1/2}} \quad (21)$$

where  $r_{ij}$  is the element of the normalized matrix that resides in the i-th column and j-th row.

Step 4: Calculate the weighted normalized matrix, V.

This can be calculated using

$$V = \{v_{ij}\} \equiv R \times W \quad (22)$$

where  $v_{ij}$  is the element of the weighted normalized matrix that resides in the i-th column and j-th row.

Step 5: Determine the positive and negative ideal solutions

Step 5.1: Positive ideal solution,  $A^+$

$$A^+ \equiv (v_1^+ \dots, v_i^+, \dots, v_m^+) = \left\{ \left( \max_j v_{ij} \mid i \in P \right), \left( \min_j v_{ij} \mid i \in N \right) \right\} \quad (23)$$

Step 5.2: Negative ideal solution,  $A^-$

$$A^- \equiv (v_1^- \dots, v_i^-, \dots, v_m^-) = \left\{ \left( \min_j v_{ij} \mid i \in P \right), \left( \max_j v_{ij} \mid i \in N \right) \right\} \quad (24)$$

where P is associated with positive criteria and N with the negative criteria.

Step 6: Calculate the relative distance of each solution from the positive ideal solution and to the negative ideal solution.

Step 6.1: Relative distance from the positive ideal solution using Euclidean metric,  $S_j^+$

$$S_j^+ = \sqrt{\sum_{i=1}^m (v_i^+ - v_{ij})^2}; j = 1, 2, \dots, n \quad (25)$$

Step 6.2: Relative distance from the negative ideal solution using Euclidean metric,  $S_j^-$

$$S_j^- = \sqrt{\sum_{i=1}^m (v_i^- - v_{ij})^2}; j = 1, 2, \dots, n \quad (26)$$

Step 7: Calculate the relative closeness of each alternative to the ideal solution; the ideal solution is 1.

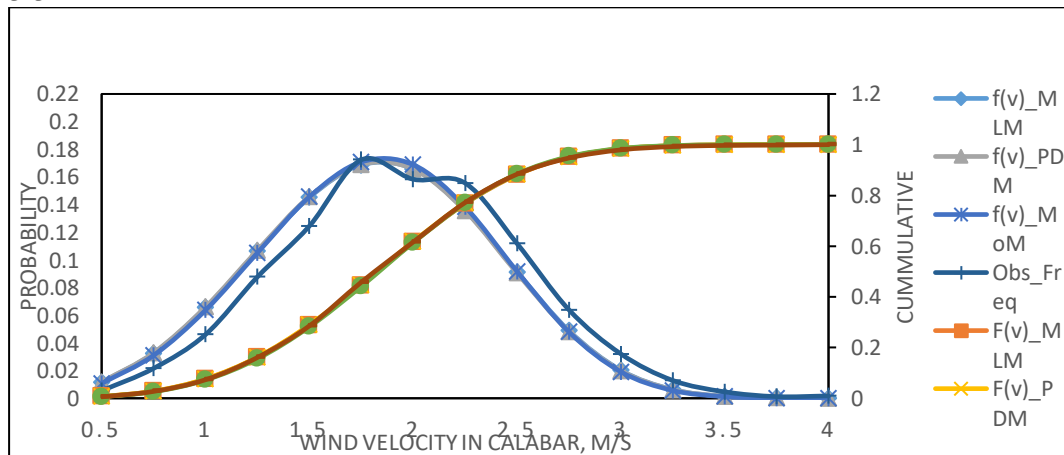
$$C_j = \frac{S_j^-}{S_j^+ + S_j^-}; 0 \leq C_j \leq 1, j = 1, 2, \dots, n \quad (27)$$

### 3.0 Results and Discussions

#### 3.1 Wind Speed Frequency Distribution and Error Analysis

Firstly, the wind speed probability curve (wind speed frequency distribution together with the respective error analysis) were calculated. The wind speed parameters were obtained using the Microsoft Excel and Easyfit 5.4 software. Thereafter, the Weibull shape and scale parameters were calculated based on the maximum likelihood method (MLM), the probability density method (PDM), and the method of moment (MOM).

The wind speed frequency distribution and the respective error analysis for the three methods for the city of Calabar is presented in Figure 3.1 and Table 3.1 to 3.3.



**Figure 3.1: Comparison of MLM, PDM and MOM for Wind Speed Distribution in the City of Calabar**

The three methods applied here were further compared among themselves according to various goodness of fit criteria which include RMSE, KS, PDE and  $R^2$ , and subsequently subjected to a multi-criteria decision analysis (TOPSIS) to decide the best alternative.

**Table 3.1 Error Analysis of the MLM Method for Wind Speed Probability Distribution**

| Month  | k [-] | c [m/s] | $R^2$    | RMSE     | KS       | PDE (%)  |
|--------|-------|---------|----------|----------|----------|----------|
| JAN    | 3.348 | 1.892   | 0.94701  | 0.014314 | 0.114609 | 0.051998 |
| FEB    | 4.009 | 2.198   | 0.902067 | 0.020012 | 0.028592 | 0.056036 |
| MAR    | 3.956 | 2.221   | 0.942095 | 0.014712 | 0.028097 | 0.230542 |
| APR    | 3.933 | 2.213   | 0.870963 | 0.022701 | 0.03706  | 0.062083 |
| MAY    | 3.723 | 2.113   | 0.853622 | 0.024736 | 0.04123  | 0.140318 |
| JUN    | 3.780 | 2.129   | 0.952633 | 0.01361  | 0.014275 | 0.197019 |
| JUL    | 3.356 | 1.944   | 0.83439  | 0.024472 | 0.039954 | 0.213117 |
| AUG    | 1.918 | 1.974   | 0.596491 | 0.035601 | 0.114609 | 40.54235 |
| SEP    | 3.508 | 2.089   | 0.925217 | 0.016223 | 0.017657 | 0.039877 |
| OCT    | 3.916 | 1.998   | 0.922094 | 0.019627 | 0.029795 | 0.239808 |
| NOV    | 3.923 | 1.824   | 0.964126 | 0.014535 | 0.029414 | 0.485081 |
| DEC    | 3.885 | 1.722   | 0.947255 | 0.018375 | 0.023839 | 0.245017 |
| ANNUAL | 3.605 | 2.026   | 0.953429 | 0.013183 | 0.012258 | 3.541937 |

**Table 3.2 Error Analysis of the PDM Method for Wind Speed Probability Distribution for Calabar**

| Month  | k [-] | c [m/s] | $R^2$    | RMSE     | KS       | PDE (%)     |
|--------|-------|---------|----------|----------|----------|-------------|
| JAN    | 3.361 | 1.893   | 0.947664 | 0.014225 | 0.218287 | 6.68397E-07 |
| FEB    | 4.031 | 2.198   | 0.902632 | 0.019954 | 0.027028 | 4.78358E-07 |
| MAR    | 3.991 | 2.220   | 0.941948 | 0.01473  | 0.030027 | 5.03702E-07 |
| APR    | 3.961 | 2.214   | 0.87187  | 0.022621 | 0.035747 | 3.72783E-07 |
| MAY    | 3.770 | 2.114   | 0.856207 | 0.024516 | 0.039626 | 1.12724E-07 |
| JUN    | 3.837 | 2.130   | 0.955118 | 0.013248 | 0.013735 | 2.45874E-06 |
| JUL    | 3.338 | 1.945   | 0.834816 | 0.024441 | 0.039574 | 3.31416E-07 |
| AUG    | 1.336 | 1.923   | 0.176941 | 0.050845 | 0.218287 | 2.69548E-05 |
| SEP    | 3.535 | 2.090   | 0.927426 | 0.015981 | 0.016829 | 8.15301E-07 |
| OCT    | 4.006 | 1.999   | 0.927079 | 0.018989 | 0.023223 | 6.08156E-07 |
| NOV    | 4.038 | 1.824   | 0.969574 | 0.013386 | 0.031168 | 7.30208E-08 |
| DEC    | 3.987 | 1.723   | 0.953459 | 0.017261 | 0.022653 | 3.00055E-06 |
| ANNUAL | 3.599 | 2.023   | 0.95072  | 0.013561 | 0.009859 | 3.0315E-06  |

**Table 3.3 Error Analysis of the MOM Method for Wind Speed Probability Distribution for Calabar.**

| Month  | k [-] | c<br>[m/s] | R <sup>2</sup> | RMSE     | KS       | PDE (%)  |
|--------|-------|------------|----------------|----------|----------|----------|
| JAN    | 3.374 | 1.892      | 0.947779       | 0.01421  | 0.106312 | 0.185121 |
| FEB    | 4.039 | 2.198      | 0.902584       | 0.019959 | 0.026594 | 0.067239 |
| MAR    | 4.028 | 2.219      | 0.941178       | 0.014828 | 0.03178  | 0.326831 |
| APR    | 3.971 | 2.213      | 0.871736       | 0.022633 | 0.035596 | 0.089842 |
| MAY    | 3.792 | 2.113      | 0.85621        | 0.024516 | 0.039628 | 0.22243  |
| JUN    | 3.873 | 2.128      | 0.955216       | 0.013233 | 0.01231  | 0.348174 |
| JUL    | 3.287 | 1.946      | 0.836149       | 0.024342 | 0.038117 | 0.735944 |
| AUG    | 1.952 | 1.992      | 0.620666       | 0.034518 | 0.106312 | 40.15221 |
| SEP    | 3.542 | 2.090      | 0.92754        | 0.015969 | 0.016367 | 0.084552 |
| OCT    | 4.046 | 1.998      | 0.927713       | 0.018906 | 0.021098 | 0.351494 |
| NOV    | 4.121 | 1.822      | 0.971105       | 0.013045 | 0.030673 | 0.702298 |
| DEC    | 4.028 | 1.722      | 0.954296       | 0.017105 | 0.021553 | 0.364962 |
| ANNUAL | 3.671 | 2.028      | 0.955653       | 0.012864 | 0.016337 | 3.635925 |

### 3.2 TOPSIS Analysis

Tables 3.4 to 3.6 shows the result for multi- criteria analysis based on the Techniques for Order of Preference by Similarity to Ideal Solution (TOPSIS) for the cities (Calabar, Port Harcourt, and Yenegoa). The alternative with relative closeness value to 1 is the best alternative, whereas the alternative with the value farthest from 1 is the worst alternative.

**Table 3.4 TOPSIS Analysis for the City of Calabar Wind Data**

**Step 1: Construct the decision matrix and determine weight of criteria**

|     | Criteria | Type | Alternatives |         |        |
|-----|----------|------|--------------|---------|--------|
|     |          |      | MLM          | PDM     | MoM    |
| Vvh | RMSE     | -    | 0.0132       | 0.0136  | 0.0129 |
| H   | KS       | -    | 0.0123       | 0.00999 | 0.0163 |
| Vvh | PDE      | -    | 3.5419       | 3.3E-06 | 3.6359 |
| H   | R2       | +    | 0.9534       | 0.9507  | 0.9557 |

**Step 2: Calculate the normalization decision matrix**

|      |   | MLM      | PDM      | MoM      |
|------|---|----------|----------|----------|
| RMSE | - | 0.575761 | 0.593208 | 0.562675 |
| KS   | - | 0.541068 | 0.439453 | 0.717026 |
| PDE  | - | 0.697787 | 6.51E-07 | 0.716306 |
| R2   | + | 0.57743  | 0.575794 | 0.578823 |

**Step 3: Calculate the weighted normalised decision matrix**

|      |   | MLM      | PDM      | MoM      |
|------|---|----------|----------|----------|
| RMSE | - | 0.14394  | 0.148302 | 0.140669 |
| KS   | - | 0.135267 | 0.109863 | 0.179256 |
| PDE  | - | 0.174447 | 1.63E-07 | 0.179076 |
| R2   | + | 0.144357 | 0.143949 | 0.144706 |

**Step 4: Determine the positive ideal and negative ideal solutions**

|      |   |          |          |
|------|---|----------|----------|
| RMSE | - | 0.140669 | 0.148302 |
| KS   | - | 0.109863 | 0.179256 |
| PDE  | - | 1.63E-07 | 0.179076 |
| R2   | + | 0.144706 | 0.143949 |

**Step 5: Calculate the separation measures from the positive ideal solution and the negative ideal solution**

|    | MLM      | PDM      | MoM      |
|----|----------|----------|----------|
| d+ | 0.176317 | 0.007671 | 0.192051 |
| d- | 0.044449 | 0.192051 | 0.007671 |

**Step 6: Calculate the relative closeness to the positive ideal solution**

|  | MLM      | PDM      | MoM      |
|--|----------|----------|----------|
|  | 0.201339 | 0.961593 | 0.038407 |

**Table 3.5 TOPSIS Analysis for the City of Port Harcourt Wind Data**

**Step 1: Construct the decision matrix and determine weight of criteria**

|     |          |      | Alternatives |          |         |
|-----|----------|------|--------------|----------|---------|
|     | Criteria | Type | MLM          | PDM      | MoM     |
| Vvh | RMSE     | -    | 0.0225       | 0.0231   | 0.02195 |
| H   | KS       | -    | 0.0789       | 0.0767   | 0.0793  |
| Vvh | PDE      | -    | 1.4388       | 6.58E-06 | 2.9677  |
| H   | R2       | +    | 0.8788       | 0.8719   | 0.8847  |

**Step 2: Calculate the normalization decision matrix**

|  |          |      | Alternatives |          |          |
|--|----------|------|--------------|----------|----------|
|  | Criteria | Type | MLM          | PDM      | MoM      |
|  | RMSE     | -    | 0.576797     | 0.592179 | 0.562698 |
|  | KS       | -    | 0.581712     | 0.565492 | 0.584662 |
|  | PDE      | -    | 0.436253     | 2E-06    | 0.899824 |
|  | R2       | +    | 0.577559     | 0.573024 | 0.581437 |

**Step 3: Calculate the weighted normalised decision matrix**

| Criteria | Type | Alternatives |          |          |
|----------|------|--------------|----------|----------|
|          |      | MLM          | PDM      | MoM      |
| RMSE     | -    | 0.144199     | 0.148045 | 0.140674 |
| KS       | -    | 0.145428     | 0.141373 | 0.146165 |
| PDE      | -    | 0.109063     | 4.99E-07 | 0.224956 |
| R2       | +    | 0.14439      | 0.143256 | 0.145359 |

**Step 4: Determine the positive ideal and negative ideal solutions**

| Criteria | Type | A+       | A-       |
|----------|------|----------|----------|
| RMSE     | -    | 0.140674 | 0.148045 |
| KS       | -    | 0.141373 | 0.146165 |
| PDE      | -    | 4.99E-07 | 0.224956 |
| R2       | +    | 0.145359 | 0.143256 |

**Step 5: Calculate the separation measures from the positive ideal solution and the negative ideal solution**

|    | Alternatives |          |          |
|----|--------------|----------|----------|
|    | MLM          | PDM      | MoM      |
| d+ | 0.109199     | 0.007664 | 0.225007 |
| d- | 0.115965     | 0.225007 | 0.007664 |

**Step 6: Calculate the relative closeness to the positive ideal solution**

|  | Alternatives |          |          |
|--|--------------|----------|----------|
|  | MLM          | PDM      | MoM      |
|  | 0.515023     | 0.967059 | 0.032941 |

**Table 3.6 TOPSIS Analysis for the City of Yenegoa Wind Data**

**Step 1: Construct the decision matrix and determine weight of criteria**

|     | Criteria | Type | Alternatives |        |        |
|-----|----------|------|--------------|--------|--------|
|     |          |      | MLM          | PDM    | MoM    |
| Vvh | RMSE     | -    | 0.0093       | 0.0271 | 0.0093 |
|     | KS       | -    | 0.0321       | 0.1137 | 0.0316 |
| H   | PDE      | -    | 1.0634       | 15.342 | 0.8478 |
| Vvh | R2       | +    | 0.9542       | 0.6164 | 0.9542 |

**Step 2: Calculate the normalization decision matrix**

| Criteria | Type | Alternatives |     |     |
|----------|------|--------------|-----|-----|
|          |      | MLM          | PDM | MoM |

|                |                                                                                                           |      |              |          |          |
|----------------|-----------------------------------------------------------------------------------------------------------|------|--------------|----------|----------|
|                | RMSE                                                                                                      | -    | 0.308735     | 0.899647 | 0.308735 |
|                | KS                                                                                                        | -    | 0.262475     | 0.929701 | 0.258386 |
|                | PDE                                                                                                       | -    | 0.069042     | 0.996094 | 0.055044 |
|                | R2                                                                                                        | +    | 0.643183     | 0.415488 | 0.643183 |
| <b>Step 3:</b> | <b>Calculate the weighted normalised decision matrix</b>                                                  |      |              |          |          |
|                | Criteria                                                                                                  | Type | Alternatives |          |          |
|                |                                                                                                           |      | MLM          | PDM      | MoM      |
|                | RMSE                                                                                                      | -    | 0.077184     | 0.0093   | 0.077184 |
|                | KS                                                                                                        | -    | 0.065619     | 0.0302   | 0.064597 |
|                | PDE                                                                                                       | -    | 0.017261     | 1.39E-05 | 0.013761 |
|                | R2                                                                                                        | +    | 0.160796     | 0.9544   | 0.160796 |
| <b>Step 4:</b> | <b>Determine the positive ideal and negative ideal solutions</b>                                          |      |              |          |          |
|                | Criteria                                                                                                  | Type | A+           | A-       |          |
|                | RMSE                                                                                                      | -    | 0.0093       | 0.077184 |          |
|                | KS                                                                                                        | -    | 0.0302       | 0.065619 |          |
|                | PDE                                                                                                       | -    | 1.39E-05     | 0.017261 |          |
|                | R2                                                                                                        | +    | 0.9544       | 0.160796 |          |
| <b>Step 5:</b> | <b>Calculate the separation measures from the positive ideal solution and the negative ideal solution</b> |      |              |          |          |
|                |                                                                                                           |      | Alternatives |          |          |
|                |                                                                                                           |      | MLM          | PDM      | MoM      |
|                | d+                                                                                                        |      | 0.797476     | 0        | 0.797363 |
|                | d-                                                                                                        |      | 0            | 0.797476 | 0.003646 |
| <b>Step 6:</b> | <b>Calculate the relative closeness to the positive ideal solution</b>                                    |      |              |          |          |
|                |                                                                                                           |      | Alternatives |          |          |
|                |                                                                                                           |      | MLM          | PDM      | MoM      |
|                |                                                                                                           |      | 0            | 1        | 0.004551 |

## 4.0 Conclusion

The Weibull parameter has been estimated using three different methods; the maximum likelihood method (MLM), the method of moment (MOM), and the probability density method (PDM). Also, a multicriteria decision method based on the technique for order of preference by similarity to ideal solution: (TOPSIS) was also used to determine which estimation method produced the best results for each site.

## REFERENCES

- Akintomide A.A, Kehinde O.O, Akintayo,T.A, Stefano, C.S. and Kehinde, O.L.(2017). Assessment of Wind Energy Potential for Small Communities in South-south Nigeria: Case Study of Koluama, Bayelsa State. *Journal of Fundamentals of renewable Energy and Applications*. 7(2), 1-6.
- Diemuodeke, E. O., Hamilton S. and Addo A. 92016). Multi-criteria Assessment of Hybrid Renewable Energy Systems for Nigeria's Coastline Communities. *Energy, Sustainability and Society*. 6(26), 1-12.
- Diemuodeke, E. O., Addo, A., Oko, C. O. C., Mulugetta, Y. and Ojapah, M. M. (2018). Optimal mapping of hybrid renewable energy systems for locations using multi-Criteria Decision – Making Algorithm. *Renewable Energy*. 134(3), 461 – 477.
- Dike, V. N. Chineke, C. T., Nwofor, O. K. and Okoro, U. K. (2011). Estimating Wind Energy Potential in some Coastal Cities of the Niger – Delta Region of Nigeria. *Pacific Journal of Science and Technology*. 12(1), 598 – 604.
- ECN-UNDP (Energy Commission of Nigeria-United Nations Development Programme) 2005. Renewable energy master plan. Final draft report. Available online [http://www.iceednigeria.org/REMP % 20Final%, 20 Report.pdf](http://www.iceednigeria.org/REMP%20Final%20Report.pdf). Retrieved on 6<sup>th</sup> May, 2018.
- Gugliani, G.K., Sarkar, A., Ley C. and Mandal S. (2018). New Methods to Assess Wind Resources in Terms of Wind Speed, Load, Power and Direction. *Renewable Energy*. 7(6), 168 – 182.
- Gadad, S. and Deka, P. C. (2016). Offshore wind power Resource Assessment Using Oceansat-2 Scatterometer Data at a Regional Scale. *Applied Energy*. 176 (3), 157-170.
- Hogan, C.M. (2013). “Niger River”, in M.Mc Ginley (ed), *Encyclopedia of Earth*. Washington DC: National Council for Science and Environment.
- Ilhan, U. (2016). An Innovative Estimation Method Regarding Weibull Parameters for Wind Energy Applications. *Energy*. 106(12), 301-314.
- Izelu, C. O, Agberegba, O. L and Oguntuberu, O. B. (2013). Wind Resource Assessment for Wind Energy Utilization in Port Harcourt, River State, Nigeria, based on weibull ProbabilityDistribution Function. *International Journal of renewable energy research*. 3(1), 22 – 30.
- Jasper Agbakwuru and Bernard Akaawase (2017). Evaluation of Wind Energy Potentials in the Nigerian Onshore and Offshore Locations. *FUPRE Journal of Scientific and Industrial Research*. Vol 1.1,(2), 26-32.

- Justus, C. G, Hargraves, W. R, Mikhail, A. and Graber, D. (1978). Methods for Estimating Wind Speed Frequency Distributions. *Journal Applied Meteorological*. 17(7), 350–353.
- Kasra, M. and Ali, M. (2013). Using Different Methods for Comprehensive Study of Wind Turbine Utilization in Zarrineh, Iran. *Energy Conversion and Management*. 6(7), 463–470.
- Melikoglu, M.(2003). Vision2023. Forecasting Turkey's Natural Gas Demand Between 2013 and 2030. *Renewable Sustainable Energy Reviews*. 22, 393, 2013-01-048.
- Mohammadi, K. and Mostafaeipour, A. (2013). Using different Methods for Comprehensive Study of Wind Turbine utilization in Zarrineh, Iran. *Energy Conversion and Management*. 65(1), 463 – 470.
- Oyedepo, S. O, Adaramola, M. S and Paul, S. S (2012). Analysis of Wind Speed Data and Wind Energy Potential in three Selected Locations in South-East Nigeria. *International Journal of Energy and Environmental Engineering*. 3(7), 1 – 11.
- Piotr, W. (2017). Two and Three-Parameter Weibull Distribution in Available Wind Power Analysis. *Renewable Energy*. 2(2), 15 – 29.
- Rao, S. and Parulekar B.B. (2004). *Energy Technology-Nonconventional, Renewable and Conventional (3<sup>rd</sup> edition)*. New Delhi: Khanna Publishers – NaiSarak.
- United Nations Development Programme (2015). Sustainable Development Goals (SDGs), <http://www.undp.org/content/undp/en/home/sdgoverview/post-2015-development-agenda.html>. Accessed 03 Feb 2016
- Uquetan, U. I. Egor, A.O., Osang, J.E and Emeruwa, C. (2015). Empirical Study of Wind Energy Potential in Calabar, Cross Rivers State, Nigeria. *International Journal of Scientific and Technology Research*. 4(10), 2277-2286.
- Ajayi, O. O., Richard D. F., James K., Julius M. N., David O. O. and Adekunle A. B, (2014). Wind energy study and energy cost of wind electricity generation in Nigeria; Past and present results and a case study for south west Nigeria, *Energies*, 7 (12), 8508-8534.
- Azad A. K. Rasul G. M. and Yusuf T. (2014). Statical diagnosis of the best Weibull methods for wind power Assessment to Agricultural Application, *Energy*, 7 (3), 3036-3085.
- Usta I. (2013) different estimation methods for the parameters of the extended Burr xii distribution, *Journal of Applied Satiation.*, 40 (2), 397-414.

Kanfar Y.M. and Usta, I. (2015), Analysis of the upper truncated Weibull Distribution for wind speed Energy Conversation Management., 96 (3), 81-88.

Comparative, estimated wind speed, TOPSIS Analysis, Weibull construct Microsoft excel and Easy fit ST4 Software.