**International Journal of Advanced Engineering and Technology**
**ISSN: 2456-7655**
**Impact Factor: RJIF 5.54**
**www.newengineeringjournal.com**
**Volume 2; Issue 2; May 2018; Page No. 42-48**

# Assessment of wind energy potential for power generation in Benin based on Weil bull distribution

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**Abstract**
Energy has been and will continue to be the driver of economy of a nation. In sharp contrast, our country Nigeria is being faced with energy poverty. This may accrue to, in part, over reliance conventional energy sources such as hydro power, fuels and gas etc. So, there is need to take into consideration the renewable energy as potential alternative for power generation. This work seeks to assess the wind energy potential of Edo state using a statistical method, two-parameter Weibull distribution function. The detailed knowledge of the wind characteristics at a site is very crucial to install and estimate the performance of a wind energy project. The monthly and yearly highest mean wind speeds were 3.28 m/s and 2.91 m/s respectively. The monthly highest values of the Weibull shape parameter (k) and the Weibull scale parameter (c) were 5.79 and 4.11 m/s. The maximum wind power density was found to be 26.76 $W/m^2$ for the year 2008.The most probable wind speed and wind speed carrying maximum energy were estimated 2.84 m/s and 4.53 m/s in 2015. The result of the study shows that the wind energy potential of Edo state is quite low for electricity generation based on the two-year wind data analysed. It is suggested that this research area should be intensified by collecting wind speed data at various locations sufficient to define its potential for power generation.

**Keywords:** wind, energy, wind energy, wind speed, weibull distribution, power generation

## 1. Introduction

Wind is a natural phenomenon related to the movement of air masses influenced primarily by the differential solar heating of the earth (Sambo, 2005) [14]. Wind is caused by differences in the atmospheric pressure. When there exists a difference in atmospheric pressure, air moves from the higher to the lower pressure area, resulting in winds of diverse speeds (Osatohanmwen *et al*., 2016) [13]. Globally, two major factors drive large scale wind patterns (the atmospheric circulation); the differential heating between the equator and the poles (difference in absorption of instantaneous electrical generation and consumption must remain in balance to maintain grid stability, these variability can present substantial challenges to incorporating large amounts of wind power into a grid system and hence statistical analysis is required to be able to study the pattern of wind flow in order to guarantee optimal wind energy power generation. To optimize the design of a wind energy conversion device, data on wind speed range over which the device must operate to maximize energy extraction is required. This in turn requires the knowledge of the frequency distribution of the wind speed. Thus for a wind energy conversion device like the wind turbine, explicit knowledge of the distribution of the wind speed is highly required to enhance output and stability of system as well as for proper wind system design.

At present Nigeria is being faced with energy crisis as it is evident in power outages and poor supply from the national grid. In part, the cause may be traced to population increment, oil price fluctuations, and climate changes among others. For very long years, combustible substances like products of crude oil, fossil fuel and woods etc., have continually remained the major energy sources which account for a large share of the national energy consumption. So, there is need to seek the potential of wind energy to generate. The environmental pollution and health hazards associated with the use of fossil fuels are another driving force towards the global switch to renewable energy. As energy has been and will still be the main stay, necessary for economic development, the Nigeria Government is seeking long-term solution to the energy crisis through the adoption of the Renewable Energy Master Plan (REMP). In order to realize this goal, the exploration of wind energy resource is one of the key elements of this master plan. Wind energy is among the potential alternatives as renewable clean energy. At present, the share of wind energy in the national energy consumption has remained on the lower end with no commercial wind. The 2- Parameter weibull distribution has been used extensively in the literature to model many wind regimes. This is due to the flexibility of the weibull model in capturing the wind distribution of many locations (Sulaiman *et al*, 2002; Sarkar and Kasperki 2009) [15, 16]. Asiegbu and Iwuoha (2007) [2] study wind energy potentials in Umudike, South-East of Nigeria and assessed its economic viability at a hub height of 65 m above the ground with annualmean wind speed of 5.36 m/s using 10 years wind speed data from the period of 1994 to 2003.Ogbonnaya *et al*. (2009) [11] on the other hand worked on the prospects of wind energy in Nigeria using 4 years of wind data from seven cities (Enugu, Jos, Ikeja, Abuja, Warri, Sokoto and Calabar). The annual wind speed at 10 m above the ground varied from 2.3 to 3.4 m/s for sites along the coastal areas and 3.0–3.9 m/s for high land areas and semi-arid regions. It was also reported that monthly average wind power was reported as 50.1 W/m2 and Sokoto is capable of a power potential as high as 97 MWh/yr. Further works by researchers are profiled in. Each of these initiatives, in the limits of their uncertainties, have identified that great prospects exist for wind energy utilization for power. Fadare (2008) [6] carriedout a statistical analysis of wind energy potential in Ibadan in Oyo State of Nigeria, using the Weibull distribution function and 10 years daily wind speed data from the period of 1995 to 2004. He reported an average wind speed and power density of 2.947 m/sand 15.484 W/m$^2$ for the City. Fagbenle *et al*. (2011) [7] carried out an assessment of wind energy potential of Maiduguri and Potiskum, two sites in north-east Nigeria with 21 years monthly mean wind data at 10m height based on weibull distribution and found out that the average monthly mean wind speed variation for potiskum ranged from 3.90 to 5.85m/s, while for Maiduguri ranged from 5.10 to 5.59m/s and The wind power density ranged from 102.54 to 300.13w/m$^2$ for potiskum and it ranged from 114.77 to 360.04w/m$^2$ for Maiduguri. Ojosu and Salawu (1990) [12] presented a statistical and cost benefit analysis of wind energy availability in different parts of the country, 15 years monthly averages (1968-1983) were used. In their analysis, he used weibull distribution methods for all the stations Maiyama *et al*. (2013) [8] carried out assessment of wind energy potentials for Electricity Generation in Sokoto, Nigeria with wind data for one year (2010), and found that the average annual wind speed for the year was 5.15m/s which is sufficient for electricity generation. Odo *et al*. (2013) [9] developed regression time series models for predicting wind potential for wind energy applications in rural locations of Nigeria and found out that wind speed correlates with ambient temperature in simple polynomial of 3$^{rd}$ degree. Dikko and Yahaya (2012) [4], carried out evaluation of wind power density in Gombe, Yola and Maiduguri, Nigeria using 12years monthly wind speed covering period of 1994 to 2005 based on weibull and Raleigh distribution and found out that weibull distribution give best fit model that describes the wind speed data at 10m height than the Raleigh models. Osatohanmwen *et al*. (2016) [13] carried out a statistical analysis of wind Energy potential in Benin city using the 2 parameters weibull distribution the results obtained indicate that weibull distribution provides a very good fit for the data, and also Benin city lies in the low wind speed Zone of the country with a relatively small wind energy output potentials. Duvuna *et al*. (2014) [5] carried out a statistical analysis of wind Energy potential Based on weibull and Rayleigh models in North-East Nigeria using sixteen (16) years mean monthly wind speed data covering the period of 1997-2012. The result show that Rayleigh is the best fit model that describes the wind speed data at 10m height and weibull model was found to present the actual probability of the wind speed data. Pilot study was carried out on wind data analysis for Benin City by Azi *et al*. (2013) [3]. The work established actual wind data at 10 metres height in Benin City. A study was also carried out on analysis of wind energy potential for power generation in Benin Based on Regression Time series by Ogbeide *et al*. (2018) [10]. The work Predicted an average wind speed of 3m/s in Benin. The essence of this study is to assess the wind energy potential of Edo state for electricity generation by using the wind data recorded at Benin airport meteorological station using statistical analysis: the weibull distribution. The result of this analysis could render relevant information to estimate wind turbine performance at a given geographical location.

## 2. Methodology

### 2.1 Research design

The research design set out to evaluate the wind energy potential for power generation. Wind speed is essentially the major input that determine the output of a given wind turbine. As a consequence of this single factor, it is necessary to have the knowledge of the wind speed characteristics. This is to say that, variability of wind speed in a typical region is important as its consideration will the efficiency and performance of wind turbine. Research design contains the population of study, samples, sampling techniques and methods of analysis alongside respective theoretical formulations on the statistical methods of analysis. The statistical tools employed in this work, is Weibull distribution analysis. For this research, Benin City is considered as the sample, within which wind speed data are collected. Then, the population of study is Edo state.

### 2.2 Source of data collection

In this study, we use 2 years (2015 to 2016) daily averages of wind speed data at 10 m meteorological height, for Benin (6.4°N; 7.0°E),obtained from the data bank of Nigerian Meteorological Agency (NIMET) located at Benin local airport. The data gives information on the daily average wind speed distributions of the locations over the study period, from which the monthly and yearly average data were calculated for the current analysis.

### 2.3 Sample and sampling techniques

As started earlier, the population of the study is Edo state. Benin airport is the geographical zone at which cup anemometer readings of wind speed data were collected. The sampling technique is purposive. Since wind speed is a random variable, for this reason statistical techniques is used. In this study, Benin Airport is the geographical location for modelling.

### 2.4 Method of data analysis

Statistical method of Weibull distribution function analysis was used to analysed the Data Obtained in this study.

#### 2.4.1 Weibull distribution function

Wind speeds have usually wide ranges and cannot be considered sufficient for obtaining a clear view of the available wind potential. In order to minimize the required time and expenses for processing long-term, usually hourly, wind speed data, it is preferred to describe the wind speed variations using statistical functions. The 2-parameter Weibull function can be used for this purpose as one can adjust the parameters to suit for a period of time, usually 1 month or 1 year. This can be used widely both in wind speed and wind energy analysis.

The wind speed probability distribution function indicates the fraction of time for which a wind speed possibly prevails at the area under investigation. The wind speed probability density function can be calculated by the following equation.

$$f(V) = (\frac{k}{c})(\frac{V}{c})^{k-1} exp\left[-\left(\frac{v}{c}\right)\right]^k \quad (1)$$

Another important aspect should be considered during the statistical analysis is the prediction of the time for which an installed turbine could be potentially functional in this area. In order to achieve this, the determination of the cumulative distribution function is required. Since the cumulative distribution function of the velocity ($v$) indicates the fraction of time the wind speed is equal or lower than speed ($v$) by taking the difference of its values, it is possible to estimate the functional time of the wind turbine. Therefore, the cumulative distribution is the integral of the probability density function and can be expressed as:

$$F(V) = 1 - exp^{-\left(\frac{V}{c}\right)^k} \quad (2)$$

The analysis of wind regime using the Weibull distribution, the Weibull parameters: shape (k) and scale (c) must be calculated.The parameter K is a dimensionless shape parameter that shows the peakedness of the distribution of the wind speed at the measuring location, and for varying values of K the distribution of the wind speed takes the shape of other distributions. For K= 1, the distribution is Exponential, for K = 2 it is Rayleigh, and for K = 3.4, the distribution becomes approximately Normal. The parameter C is the scale parameter measured also in m/s and it shows how windy the location of the measuring site is.

Some of the methods used for determining k and c are Weibull probability plotting method, Moment method, Energy pattern factor method, Standard deviation method, Maximum likelihood method etc. Though all the above mentioned methods are widely used, in this study standard deviation method has been used. For calculating the mean wind speed ($v$), the following equation can be used:

$$Vm = \frac{1}{n}\left[\sum_{i=0}^{n} V_i\right] \quad (3)$$

By calculating the mean wind speed ($v$) and the variance σ of the known wind speed data, the following approximation can be used to calculate the Weibull parameters c and k:

$$\sigma = \left[\frac{1}{n-1}\sum_{i=1}^{n}(V_i - Vm)^2\right]^{\frac{1}{2}} \quad (4)$$

$$k = \left[\frac{\sigma}{Vm}\right]^{-1.086} \quad 1 \le k \le 10 \quad (5)$$

$$c = \frac{Vm}{\Gamma\left(1+\frac{1}{k}\right)} \quad (6)$$

**2.4.2 Most Probable Wind Speed**

The most probable wind speed denotes the most frequent wind speed for a given wind probability distribution. From the scale parameter and shape parameter of Weibull distribution function, the most probable wind speed can be easily obtained from the following equation 7:

$$V_{mp} = c\left(1 - \frac{1}{k}\right)^{\frac{1}{k}} \quad (7)$$

**2.4.3 Maximum energy carrying by the wind speed**

The maximum wind energy carrying by the wind speed can be calculated from the scale parameter and shape parameter of Weibull distribution function. The wind speed which is carrying maximum wind energy can be expressed as follows:

$$V_{max.E} = c(1 + \frac{2}{k})^{\frac{1}{k}} \quad (8)$$

**2.4.4 Wind power density**

The power of the wind that flows at a speed (v) through a blade sweep area (A) can be expressed by the following equations:

$$P(V) = \frac{1}{2}\rho V^3 \quad (9)$$

Besides, calculation of wind power density based on the wind speed provided by field measurements can be developed by Weibull distribution analysis using the following equation:

$$\frac{P}{A} = \int_0^{\infty} \frac{1}{2}\rho V^3 f(V)dv = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right) \quad (10)$$

Where, $\rho$ is the standard air density at sea level with mean temperature of 15°C and 1 atmospheric pressure that is 1.225 kg/m3 which, depends on altitude, air pressure and temperature. It is also seen from the above equation that wind power density increases with the cube of the wind speed.

**3. Results**

The daily mean wind speed collected from the Nigeria Meteorological Agency (NIMET), Benin City Edo state is Presented. It also contains the data result, analysis and discussion. As stated earlier, statistical methods are adopted in the computation, description and analysis of wind speeds for a period of two-year (2015-2016). In order to estimate the wind energy potential in Benin, two parameter Weibull distribution analysis is the statistical methods employed to achieve the aim of study.

The wind speed data, collected from NIMET, are displayed in Table 1 and Table 2. The unit of speed used, is meters per second.

**Table 1:** Daily records of wind speed for the year 2015

| Days | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.018 | 6.001 | 3.133 | 1.652 | 3.938 | 2.621 | 1.853 | 3.289 | 2.123 | 3.648 | 2.042 | 2.325 |
| 2 | 2.160 | 4.093 | 2.784 | 1.744 | 2.404 | 3.065 | 3.183 | 3.379 | 2.969 | 2.858 | 2.173 | 2.553 |
| 3 | 2.485 | 3.952 | 2.263 | 2.046 | 3.197 | 1.948 | 2.769 | 3.759 | 2.778 | 2.687 | 1.308 | 3.977 |
| 4 | 3.993 | 3.723 | 2.373 | 2.374 | 2.643 | 2.884 | 2.508 | 4.228 | 1.515 | 2.346 | 2.488 | 3.342 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 3.171 | 1.436 | 2.257 | 2.389 | 3.364 | 2.816 | 2.214 | 3.866 | 2.868 | 2.658 | 1.815 | 3.090 |
| 6 | 2.744 | 3.435 | 2.563 | 1.880 | 2.713 | 3.037 | 1.746 | 3.882 | 1.362 | 2.041 | 1.652 | 2.861 |
| 7 | 3.427 | 4.610 | 3.379 | 2.037 | 3.046 | 1.210 | 3.354 | 3.876 | 3.037 | 2.022 | 1.963 | 4.225 |
| 8 | 4.305 | 3.631 | 3.269 | 2.394 | 3.124 | 2.868 | 2.789 | 2.870 | 2.816 | 2.191 | 2.243 | 2.536 |
| 9 | 4.568 | 2.148 | 2.789 | 3.148 | 2.583 | 1.515 | 3.269 | 2.879 | 2.884 | 2.786 | 2.342 | 2.478 |
| 10 | 4.467 | 3.515 | 3.354 | 1.917 | 3.032 | 2.778 | 3.379 | 5.135 | 1.948 | 2.159 | 1.738 | 2.157 |
| 11 | 5.134 | 2.840 | 1.746 | 2.195 | 3.269 | 2.969 | 2.564 | 3.900 | 3.065 | 2.167 | 1.793 | 3.084 |
| 12 | 5.956 | 2.646 | 2.214 | 1.628 | 2.175 | 2.153 | 2.257 | 2.884 | 2.621 | 1.723 | 1.706 | 2.285 |
| 13 | 3.626 | 2.369 | 2.508 | 1.209 | 2.515 | 1.704 | 2.373 | 2.845 | 2.243 | 2.749 | 2.428 | 1.793 |
| 14 | 2.472 | 2.721 | 2.769 | 1.631 | 4.728 | 1.673 | 2.263 | 3.564 | 1.458 | 1.339 | 2.612 | 2.441 |
| 15 | 2.460 | 3.405 | 3.502 | 1.926 | 2.647 | 2.783 | 2.784 | 3.152 | 3.404 | 2.022 | 2.030 | 3.229 |
| 16 | 2.450 | 3.499 | 3.183 | 1.994 | 2.381 | 3.818 | 3.133 | 4.227 | 3.707 | 2.474 | 1.912 | 2.879 |
| 17 | 2.070 | 3.893 | 1.853 | 1.501 | 3.602 | 1.980 | 3.438 | 4.520 | 3.510 | 2.387 | 2.094 | 2.728 |
| 18 | 3.914 | 2.687 | 2.387 | 1.586 | 2.970 | 3.510 | 2.806 | 2.509 | 1.980 | 2.090 | 1.438 | 2.640 |
| 19 | 3.422 | 4.059 | 2.811 | 1.893 | 1.972 | 3.707 | 1.559 | 3.022 | 3.818 | 2.284 | 1.690 | 2.469 |
| 20 | 3.693 | 2.903 | 3.124 | 1.756 | 3.584 | 3.396 | 3.546 | 3.380 | 2.783 | 2.122 | 2.016 | 2.370 |
| 21 | 3.670 | 1.100 | 3.639 | 2.015 | 3.342 | 1.458 | 3.124 | 2.581 | 1.673 | 2.315 | 1.749 | 3.468 |
| 22 | 4.377 | 4.519 | 1.559 | 2.614 | 2.909 | 2.243 | 2.811 | 3.850 | 1.704 | 3.151 | 1.282 | 4.283 |
| 23 | 4.844 | 3.471 | 2.806 | 2.769 | 2.281 | 3.139 | 2.387 | 2.761 | 3.503 | 1.968 | 1.929 | 2.662 |
| 24 | 4.907 | 2.989 | 3.426 | 2.392 | 2.400 | 3.503 | 2.978 | 2.469 | 2.807 | 1.882 | 2.012 | 5.080 |
| 25 | 4.777 | 1.719 | 3.327 | 2.962 | 2.164 | 2.569 | 2.826 | 3.375 | 3.306 | 2.358 | 1.759 | 3.710 |
| 26 | 3.843 | 3.004 | 2.960 | 1.298 | 1.490 | 2.807 | 4.405 | 3.074 | 3.304 | 2.601 | 2.727 | 2.707 |
| 27 | 4.522 | 2.803 | 3.032 | 2.607 | 2.819 | 2.944 | 1.194 | 4.506 | 3.162 | 2.198 | 3.220 | 2.476 |
| 28 | 4.416 | 1.031 | 2.978 | 2.177 | 2.700 | 3.306 | 3.032 | 2.493 | 2.944 | 1.860 | 2.215 | 1.641 |
| 29 | 4.148 | | 2.826 | 2.390 | 2.052 | 3.162 | 2.960 | 2.963 | 2.569 | 1.080 | 2.619 | 2.040 |
| 30 | 3.225 | | 4.405 | 2.534 | 1.237 | 3.304 | 3.426 | 3.306 | 3.139 | 1.594 | 2.552 | 2.094 |
| 31 | 4.420 | | 1.194 | | 2.561 | | 3.327 | 4.239 | | 2.131 | | 2.099 |

**Table 2:** Daily records of wind speed for the year, 2016

| days | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEPT | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.531 | 2.080 | 3.724 | 3.257 | 3.269 | 2.576 | 2.404 | 3.032 | 3.440 | 2.840 | 1.463 | 2.128 |
| 2 | 3.551 | 2.399 | 3.952 | 3.171 | 3.032 | 1.910 | 2.197 | 3.381 | 2.974 | 3.056 | 2.608 | 1.560 |
| 3 | 2.634 | 3.316 | 4.093 | 3.192 | 2.583 | 2.454 | 2.643 | 2.381 | 3.815 | 3.267 | 2.019 | 1.318 |
| 4 | 2.322 | 4.516 | 6.001 | 3.352 | 3.124 | 3.151 | 3.383 | 3.602 | 2.997 | 1.861 | 1.666 | 1.694 |
| 5 | 1.911 | 3.545 | 1.436 | 5.241 | 3.046 | 2.253 | 2.713 | 4.743 | 2.840 | 2.757 | 1.706 | 2.538 |
| 6 | 2.035 | 2.662 | 2.840 | 3.616 | 2.713 | 3.395 | 3.046 | 2.700 | 3.082 | 2.340 | 2.423 | 2.076 |
| 7 | 2.072 | 3.273 | 3.515 | 2.703 | 3.364 | 1.513 | 3.124 | 2.561 | 3.649 | 3.015 | 2.673 | 2.493 |
| 8 | 2.832 | 3.760 | 2.148 | 3.530 | 2.643 | 2.598 | 2.583 | 2.052 | 3.955 | 3.176 | 1.615 | 2.326 |
| 9 | 4.080 | 2.566 | 3.632 | 2.809 | 3.197 | 1.636 | 3.032 | 2.292 | 3.749 | 2.319 | 2.682 | 2.221 |
| 10 | 3.341 | 2.201 | 4.610 | 1.975 | 2.404 | 2.924 | 3.269 | 2.666 | 3.295 | 2.146 | 2.857 | 2.677 |
| 11 | 2.762 | 3.385 | 3.436 | 3.275 | 3.938 | 3.082 | 3.500 | 3.584 | 4.482 | 2.202 | 2.992 | 2.399 |
| 12 | 3.237 | 3.338 | 3.698 | 1.945 | 2.175 | 1.529 | 2.909 | 1.972 | 4.147 | 0.873 | 1.669 | 2.669 |
| 13 | 2.929 | 4.017 | 3.004 | 3.026 | 2.515 | 2.289 | 2.381 | 2.404 | 1.932 | 2.572 | 1.375 | 2.164 |
| 14 | 2.576 | 3.134 | 1.719 | 4.371 | 4.937 | 3.515 | 3.602 | 2.164 | 2.188 | 1.005 | 1.972 | 1.551 |
| 15 | 3.269 | 3.606 | 2.989 | 1.593 | 2.647 | 2.080 | 2.970 | 2.400 | 2.692 | 3.205 | 2.518 | 2.156 |
| 16 | 3.219 | 4.886 | 3.471 | 2.988 | 2.970 | 1.189 | 2.647 | 2.909 | 2.803 | 1.547 | 2.947 | 2.288 |
| 17 | 2.726 | 5.028 | 4.519 | 3.054 | 3.602 | 2.405 | 4.937 | 3.197 | 2.036 | 2.069 | 1.635 | 1.349 |
| 18 | 2.043 | 3.401 | 1.100 | 2.519 | 2.381 | 3.676 | 2.515 | 2.040 | 2.621 | 1.897 | 1.597 | 2.279 |
| 19 | 2.121 | 5.704 | 2.903 | 1.921 | 2.909 | 2.703 | 2.175 | 3.371 | 3.502 | 2.798 | 1.937 | 2.634 |
| 20 | 1.547 | 3.941 | 4.045 | 2.720 | 3.497 | 2.735 | 3.862 | 2.713 | 2.339 | 1.989 | 2.288 | 1.925 |
| 21 | 3.012 | 4.572 | 2.551 | 2.240 | 3.584 | 2.237 | 2.281 | 3.497 | 1.562 | 1.856 | 2.911 | 1.821 |
| 22 | 2.128 | 3.194 | 3.893 | 3.379 | 1.972 | 2.033 | 2.700 | 2.643 | 2.716 | 2.015 | 2.184 | 2.904 |
| 23 | 2.536 | 4.644 | 3.499 | 3.976 | 2.164 | 3.148 | 2.561 | 2.970 | 1.670 | 2.045 | 1.669 | 2.380 |
| 24 | 2.651 | 3.039 | 3.405 | 3.725 | 2.400 | 2.423 | 2.052 | 2.281 | 1.636 | 2.122 | 2.070 | 2.310 |
| 25 | 3.783 | 3.655 | 2.721 | 2.513 | 1.490 | 2.887 | 1.237 | 3.046 | 3.212 | 1.888 | 2.396 | 2.839 |
| 26 | 3.345 | 3.667 | 2.369 | 2.752 | 2.281 | 3.540 | 2.666 | 3.862 | 1.867 | 2.345 | 2.478 | 2.962 |
| 27 | 4.524 | 3.061 | 2.481 | 4.316 | 3.985 | 2.931 | 3.584 | 2.739 | 1.754 | 2.571 | 2.989 | 2.855 |
| 28 | 3.082 | 4.786 | 2.646 | 2.175 | 2.700 | 3.463 | 1.972 | 3.124 | 2.571 | 1.682 | 2.974 | 2.576 |
| 29 | 4.395 | 4.332 | 3.131 | 2.548 | 2.561 | 3.852 | 2.164 | 2.515 | 2.511 | 2.645 | 1.996 | 2.157 |
| 30 | 2.253 | | 2.968 | 2.938 | 2.052 | 3.880 | 2.400 | 2.175 | 2.067 | 2.322 | 2.643 | 1.515 |
| 31 | 1.759 | | 3.954 | | 1.237 | | 1.490 | 2.583 | | 2.769 | | 1.572 |

## 4. Two-Parameter weibull distribution analysis

The Weibull distribution parameters Shape (k), Scale (c) and standard deviation, $\sigma$ were calculated using the measured wind speed data based on equation (4), (5) and (3) respectively. The computations were carried out with Microsoft Excel and thus, the results are given in the Table 3

**Table 3:** Monthly values of Weibull parameters and standard deviation of wind speed (2015)

| Qty | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $k$ | 4.121 | 3.150 | 4.735 | 4.994 | 4.454 | 4.286 | 4.763 | 5.787 | 4.349 | 5.032 | 5.336 | 4.040 |
| $c$ | 4.110 | 3.520 | 3.048 | 2.276 | 3.037 | 2.967 | 3.036 | 3.716 | 2.965 | 2.450 | 2.224 | 3.121 |
| $\sigma$ | 1.013 | 1.095 | 0.666 | 0.475 | 0.700 | 0.707 | 0.660 | 0.683 | 0.698 | 0.508 | 0.439 | 0.782 |

**Table 4:** k, c and $\sigma$ values for the year, 2016.

| Qty | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $k$ | 4.208 | 4.629 | 3.647 | 4.225 | 4.175 | 4.119 | 4.240 | 5.186 | 3.863 | 4.349 | 4.821 | 5.312 |
| $c$ | 3.091 | 3.993 | 3.593 | 3.332 | 3.104 | 2.941 | 3.013 | 3.076 | 3.095 | 2.525 | 2.434 | 2.388 |
| $\sigma$ | 0.748 | 0.890 | 0.984 | 0.804 | 0.757 | 0.725 | 0.725 | 0.622 | 0.807 | 0.594 | 0.524 | 0.473 |

From the results obtained, the wind power density can be estimated using Weibull scale parameters, k and c using equation (8). The estimated power density are shown in table (4). Also, the monthly characteristic speeds, $V_{mp}, V_{max.E}$ were calculated using equation (7), (8) and the results are shown in the table below.

**Table 5:** Monthly characteristic speeds and wind power density.

| Month | Parameter | 2015 | 2016 | | Parameters | 2015 | 2016 |
|---|---|---|---|---|---|---|---|
| Jan | $P/A$ | 38.888 | 16.485 | Jul | $P/A$ | 15.383 | 15.245 |
| | $V_{mp}$ | 3.842 | 2.898 | | $V_{mp}$ | 2.890 | 2.828 |
| | $V_{max.E}$ | 4.525 | 3.391 | | $V_{max.E}$ | 3.268 | 3.300 |
| Feb | $P/A$ | 26.192 | 35.092 | Aug | $P/A$ | 27.865 | 15.884 |
| | $V_{mp}$ | 3.118 | 3.789 | | $V_{mp}$ | 3.596 | 2.951 |
| | $V_{max.E}$ | 4.114 | 4.315 | | $V_{max.E}$ | 3.911 | 3.275 |
| Mar | $P/A$ | 15.74 | 26.638 | Sep | $P/A$ | 14.470 | 16.808 |
| | $V_{mp}$ | 2.899 | 3.291 | | $V_{mp}$ | 2.792 | 2.864 |
| | $V_{max.E}$ | 3.284 | 4.051 | | $V_{max.E}$ | 3.234 | 3.448 |
| Apr | $P/A$ | 6.457 | 20.639 | Oct | $P/A$ | 14.470 | 8.944 |
| | $V_{mp}$ | 2.177 | 3.126 | | $V_{mp}$ | 2.792 | 2.378 |
| | $V_{max.E}$ | 2.435 | 3.652 | | $V_{max.E}$ | 3.234 | 2.755 |
| May | $P/A$ | 15.511 | 16.705 | Nov | $P/A$ | 5.998 | 7.915 |
| | $V_{mp}$ | 2.869 | 2.907 | | $V_{mp}$ | 2.140 | 2.319 |
| | $V_{max.E}$ | 3.201 | 3.409 | | $V_{max.E}$ | 2.361 | 2.616 |
| Jun | $P/A$ | 14.537 | 14.242 | Dec | $P/A$ | 17.073 | 7.421 |
| | $V_{mp}$ | 2.789 | 2.749 | | $V_{mp}$ | 2.908 | 2.296 |
| | $V_{max.E}$ | 3.244 | 3.237 | | $V_{max.E}$ | 3.447 | 2.536 |

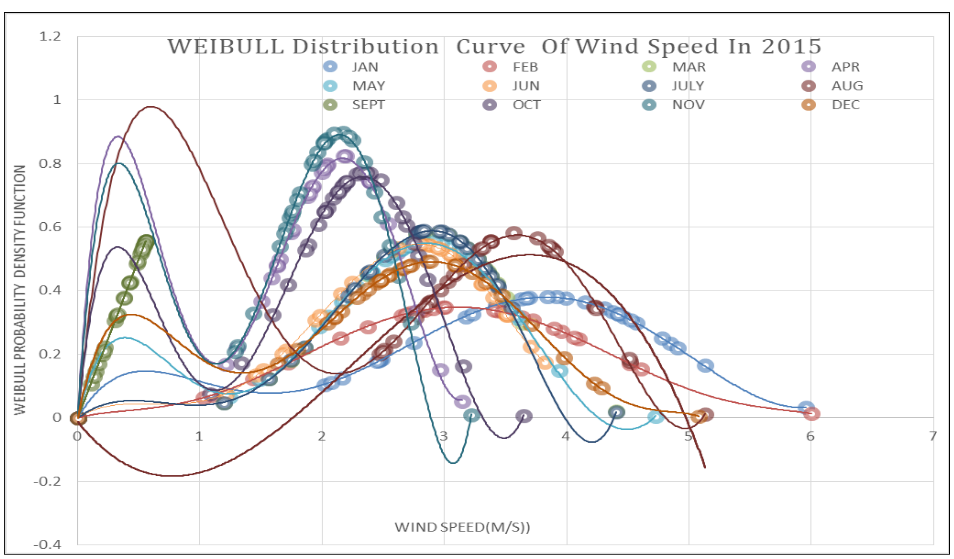


**Fig 1:** Weibull distribution curves showing monthly wind speed characteristics in 2015.

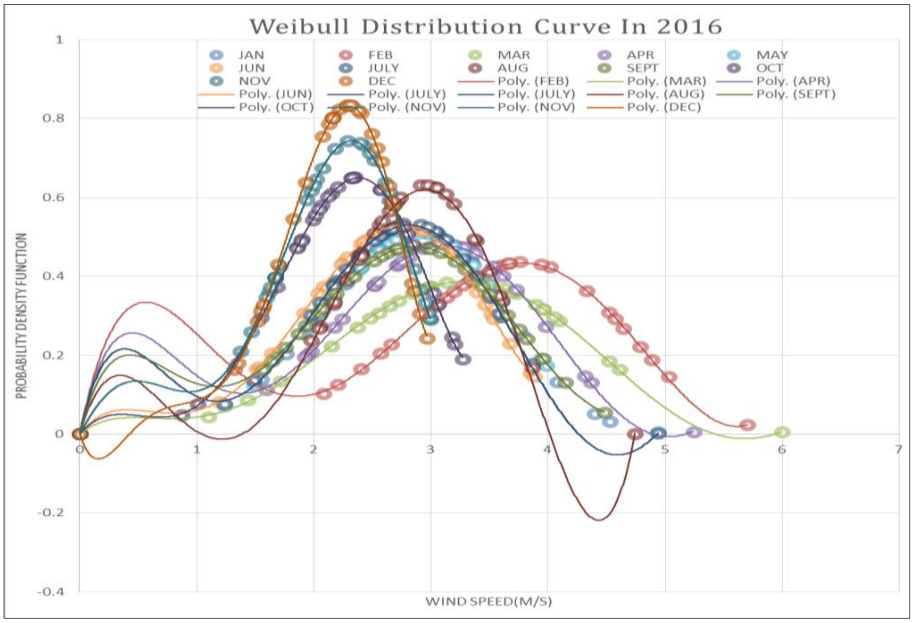


**Fig 2:** Weibull distribution curves showing monthly wind speed characteristics in 2016.

## 5. Discussion

The determination of the wind potential of the selected sites was made by analysing in detail the wind characteristics, such as the mean wind speed, the resulting power density. The daily wind speed recorded for the 2015 and 2016 is Presented in Table 1 and Table 2 respectively it is obvious from the Tables that the highest daily wind speed recorded in 2015 was 6.001m/s on the 1st of February while 2016 was 6.001m/s on the 4th of March which was high and sufficient to generate electricity for that day. While the lowest daily wind speed recorded in 2015 and 2016 was1.031m/s on 28th February and 0.873m/s on 12th October which was very low and insufficient for electricity generation for that day. The monthly calculated mean wind speed, power and power density and their corresponding predicted values was presented in Table 3. Results shows that wind speed decreases with power and power density and increase in wind speed also increases the power and the power density which shows that power is directly proportional to the cube of wind speed. The results was also justify as represented in Figure1, Figure2, Figure3 and Figure4 showing a non linear relationship between power and wind speed which is as a result of the cube of the wind velocity. From the Figures, the higher the wind speed, the higher the power and the higher the power density. A look at the probabilitydensity in figures 1 and 2 clearly shows that the Weibull distribution provides a very good fit for the data. This is also emphasized by the results of the standard deviation (error) contained in Table 3 and Table 4 which supports a very good fit of the Weibull distribution to the observed wind speed data.From Table 5 we see that the Benin City is capable of generating a power output of 1.2545W/m$^2$daily, which is quite a small amount of power output. This however shows that the city lies in the low wind speed zone in the country with small amount of wind resources. It can also be seen from the 2-parameter Weibull analysis, that there are dramatic monthly changes in the wind power density obtained in Table (5) with a maximum value (38.88 W/m$^2$ in January) being 5.24 times of the minimum (7.42 W/m$^2$) in December). Such considerable amount of difference in wind power density is seen because the power is proportional to the cube of the wind speed. When a wind project will be assessed or designed, this significant difference from month to month will underscore the performance of the installed wind turbine. Osatohanmwen *et al*. [11] applied Weibull distribution to determined wind power density in Benin City using five year daily average wind speed data obtained from National Center for Energy and Environment in University of Benin, whereas the present study used two year data obtained from Nigeria Meteorological Agency Benin and results was in agreement with little difference compared with the latter

## 6. Conclusion

In this assessment two-year data of one station has been analysed. The analysis has been done based on 2-parameter Weibull distribution function. The crucial outcomes of this study are summarized below:

- The highest of the monthly average wind speed recorded for the years, 2015 and 2016 are 3.731m/s and 3.645m/s respectively.
- The yearly mean wind speeds were found to be 2.774m/s and 2.787m/s in 2015 and 2016 respectively.
- The maximum wind power density has been found to be 31.83$W/m^2$ in January, 2015.

It has been shown that the weibull distribution is highly adequate in modelling the wind speed of Benin City. This is very important because the choice of the distribution used in modelling observed wind speed plays a very crucial role in wind power analysis.

At the end, it can be concluded that it will not be economical to generate electricity from this site. A wind turbine usually needs wind speeds of around 5-6 m/s to generate electricity. However, there are some latest wind turbines particularly vertical axis models that can generate electricity with as little as around 2.3 m/s wind speed.

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