# Wind Energy Potential of Maiduguri, Borno State, Nigeria

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**Abstract:** ***The wind characteristics of Maiduguri were examined in this paper. Available monthly data show that there is abundant wind. The analysis further shows that the wind is sufficient to support the establishment of a wind turbine with a cut-in-speed of 3.2 m/s, which can generate 4.65 W of electricity at 140 m hub height. It was also shown that if a wind turbine of 11,000 $m^2$ swept area is used, 51.2 kW of electricity, for a small scale wind power, can be generated. This makes the establishment of wind farm feasible and, therefore, recommended.***

**Keywords:** cut-in-speed, wind energy, Weibull model, extractable power, wind farm

## 1. Introduction

Wind consists of bulk movement of air from high to low pressure regions. Wind has three important aspects: velocity (wind speed), density of the gas involved and energy content or wind energy. The wind energy potential is the power available from the kinetic energy of the bulk of air moving in wind. The kinetic energy in the wind is converted into electricity using wind turbines. Hence, wind energy is inexhaustible and contributes very little pollution and few greenhouse gases to the environment and is therefore a valuable alternative to non-renewable and depleting fossil fuel.

Because of its environmental friendliness, there is a global boost in wind power generation. As of 2015, Demark generates 40% of its electricity from wind and at least 83 other countries around the world are using wind power to supply their electricity grids [1]. Yearly, wind energy production is also growing rapidly and has reached around 4% of worldwide electricity usage [2], 11.4% in the EU [3]. Nigeria is yet to key into this global trend despite its wind energy potential.

To make proper use of wind energy, proper site selection and wind speed availability are to be considered first. The wind speed and its duration are the key factors to design and to determine the use of wind energy. The primary purpose of this paper is to examine the wind speed characteristics of Maiduguri so that its potential for wind power production can be properly placed.

## 2. The Data

The data are on the monthly wind speed obtained from the Nigerian Meteorological Agency (NiMET) Office in Maiduguri, at hub height of 10 meters. The period covered by the data is September, 1985 to December, 2011. The data are shown in Table 2.1 below

**Table 2.1:** Wind Speed Data for Maiduguri

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | | | | | | | | | | | | |
| 1985 | | | | | | | | | 3.06 | 3.98 | 3.66 | 4.02 |
| 1986 | 3.48 | 3.93 | 4.54 | 4.93 | 4.51 | 6.22 | 5.27 | 4.11 | 3.46 | 3.00 | 3.26 | 4.04 |
| 1987 | 3.50 | 3.85 | 3.95 | 5.53 | 5.44 | 4.87 | 5.39 | 3.71 | 3.62 | 2.23 | 3.57 | 2.43 |
| 1988 | 3.77 | 4.48 | 4.89 | 4.37 | 4.47 | 5.78 | 5.59 | 3.98 | 3.53 | 3.14 | 3.25 | 3.64 |
| 1989 | 4.52 | 4.94 | 4.32 | 4.15 | 4.94 | 5.55 | 5.22 | 3.89 | 3.30 | 3.33 | 3.39 | 3.29 |
| 1990 | 3.90 | 4.52 | 5.53 | 4.29 | 5.07 | 5.38 | 4.51 | 4.06 | 3.30 | 3.33 | 3.28 | 3.46 |
| 1991 | 3.74 | 3.60 | 4.46 | 4.64 | 4.29 | 4.79 | 4.18 | 3.17 | 3.24 | 2.97 | 3.42 | 3.37 |
| 1992 | 3.92 | 4.70 | 4.16 | 4.41 | 4.54 | 5.23 | 4.40 | 3.69 | 2.57 | 2.42 | 3.16 | 2.70 |
| 1993 | 3.77 | 1.74 | 4.02 | 3.86 | 4.77 | 4.53 | 4.00 | 3.25 | 2.85 | 2.75 | 2.91 | 3.35 |
| 1994 | 3.46 | 3.82 | 4.63 | 3.83 | 3.89 | 4.96 | 4.31 | 3.26 | 2.36 | 2.69 | 3.00 | 2.78 |
| 1995 | 2.85 | 3.24 | 4.08 | 4.22 | 4.15 | 5.01 | 4.05 | 2.55 | 2.45 | 1.64 | 2.49 | 2.78 |
| 1996 | 2.26 | 2.73 | 3.47 | 3.36 | 3.93 | 3.63 | 3.39 | 2.61 | 2.42 | 2.14 | 2.30 | 1.93 |
| 1997 | 2.82 | 4.18 | 3.72 | 3.45 | 3.49 | 3.49 | 3.48 | 2.27 | 2.12 | 2.09 | 2.16 | 2.25 |
| 1998 | 3.32 | 3.80 | 2.87 | 3.35 | 3.69 | 6.24 | 3.17 | 4.31 | 4.92 | 1.00 | 1.67 | 2.15 |
| 1999 | 2.32 | 2.69 | 2.94 | 3.71 | 3.53 | 3.58 | 3.28 | 2.46 | 2.11 | 1.91 | 2.08 | 2.19 |
| 2000 | 2.72 | 3.46 | 3.35 | 2.85 | 3.48 | 4.14 | 3.44 | 2.79 | 3.19 | 2.22 | 2.80 | 2.80 |
| 2001 | 2.86 | 3.53 | 3.68 | 3.84 | 4.30 | 4.21 | 3.91 | 2.96 | 2.57 | 2.16 | 5.10 | 1.81 |
| 2002 | 2.81 | 1.88 | 2.67 | 2.92 | 3.11 | 3.97 | 3.78 | 2.88 | 2.46 | 2.05 | 2.05 | 2.28 |
| 2003 | 1.56 | 1.44 | 2.16 | 2.65 | 2.75 | 2.26 | 1.51 | 0.90 | 1.59 | 2.18 | 2.40 | 2.38 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2004 | 2.23 | 3.18 | 3.51 | 2.90 | 3.87 | 3.61 | 2.99 | 2.70 | 2.32 | 1.81 | 1.72 | 1.61 |
| 2005 | 2.42 | 2.51 | 2.97 | 2.94 | 2.92 | 3.09 | 2.63 | 1.82 | 1.64 | 1.51 | 1.59 | 1.08 |
| 2006 | 1.48 | 2.39 | 2.87 | 3.25 | 3.50 | 4.13 | 6.24 | 2.86 | 2.70 | 2.53 | 1.86 | 2.17 |
| 2007 | 3.12 | 2.91 | 3.29 | 3.59 | 3.61 | 3.91 | 3.24 | 2.19 | 1.91 | 2.13 | 1.86 | 2.17 |
| 2008 | 2.56 | 2.60 | 2.10 | 2.59 | 2.67 | 2.75 | 2.52 | 1.93 | 1.72 | 1.82 | 1.54 | 1.51 |
| 2009 | 1.43 | 1.85 | 2.12 | 2.19 | 1.80 | 2.55 | 2.45 | 1.75 | 1.26 | 1.28 | 1.05 | 1.31 |
| 2010 | 0.90 | 1.26 | 1.65 | 1.74 | 1.70 | 1.98 | 1.64 | 1.21 | 1.11 | 0.90 | 0.84 | 0.85 |
| 2011 | 1.44 | 1.96 | 1.68 | 2.48 | 1.96 | 1.68 | 1.30 | 3.40 | 1.06 | 1.06 | 1.07 | 1.13 |

Source: NiMET, Maiduguri Office

## 3. The Model

In times of economic value, the wind energy sector has become one of the important players in the energy market with the total value of new equipment installed in 2007 reaching €25 billion [4]. Therefore there is a global shift in the energy market consequent upon the use of wind energy as an alternative source of electricity generation.

Understanding wind speed characteristics is very crucial in wind energy generation. Considerable time has therefore been devoted to modeling of wind speed. From all these studies Weibull and Rayleigh distributions have been found to be appropriate. The Weibull probability density function is given by

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

and its special case, the Raleigh distribution, obtains when the shape parameter ($k$) is 2

Examples of the application of this model to wind speed data can be found in [5], [6], [7] and [8]. In Gongsin and Saporu [7] estimation of Weibull model parameters by maximum likelihood, regression, method of moments and optimization methods were discussed. Parameter estimates were also obtained for Maiduguri wind speed data. The maximum likelihood estimates are presented in Table 3.1.

**Table 3.1:** Weibull Model Maximum Likelihood Parameter Estimates

| Month | $c$ | Se($c$) | $k$ | Se($k$) |
|---|---|---|---|---|
| January | 3.12 | .191 | 3.42 | .566 |
| February | 3.47 | .208 | 3.34 | .559 |
| March | 3.82 | .197 | 3.99 | .659 |
| April | 3.86 | .188 | 4.26 | .698 |
| May | 4.10 | .183 | 4.62 | .729 |
| June | 4.60 | .253 | 3.83 | .616 |
| July | 4.13 | .252 | 3.39 | .521 |
| August | 3.11 | .187 | 3.43 | .549 |
| September | 2.91 | .180 | 3.34 | .486 |
| October | 2.49 | .160 | 3.22 | .490 |
| November | 2.81 | .203 | 2.81 | .413 |
| December | 2.72 | .185 | 3.04 | .473 |

Se = Standard Error

## 4. The Problem

Borno State covers an area of 70,898 km$^2$ in the North-East of Nigeria. It occupies greater part of the Lake Chad Basin and agriculture is the main stay of its inhabitants. The state capital is Maiduguri with coordinate 11.9° N, 13.1° E and altitude 354 m [9] above sea level. The yearly average temperature and rainfall are 25.8° C and 613 mm, respectively [10]. The monthly climate details are given in Table 4.1 below.

Table 4.1 shows that there is availability of abundant sunshine throughout the year. It is well known that wind energy is derivable from solar energy. Hence, the availability of abundant sunshine gives an indication of the wind energy potential of Maiduguri. A recorded yearly average wind speed of 3 m/s further confirms this. What remains is an expository study of the wind characteristics of Maiduguri to highlight the salient features of its wind energy potentials. This is the primary concern of this paper.

**Table 4.1:** Maiduguri Climatic Data

| Month | Average | |
|---|---|---|
| | Temperature (°C) | Rainfall (mm) |
| January | 21.4 | 0 |
| February | 23.4 | 0 |
| March | 27.1 | 1 |
| April | 29.7 | 10 |
| May | 30 | 33 |
| June | 28.4 | 78 |
| July | 26.1 | 164 |
| August | 24.8 | 215 |
| September | 26.1 | 99 |
| October | 26.7 | 13 |
| November | 24.1 | 0 |
| December | 21.4 | 0 |

## 5. Definition of Terms

Before we commence further discussion, there are relevant definitions that will enhance the understanding of this paper. For any given turbine, there are some important characteristics of wind speed. These are defined below.

Definitions:
1) Cut-in-speed is the lowest wind speed at which a turbine can generate usable power.
2) The rated-speed (typically between 12 and 16 m/s) is the lowest speed at which a turbine operates at its rated capacity i.e. at maximum power output.
3) Cut-out-speed is the lowest wind speed at which there is the potential of damage to the turbine, if operation continues.
4) Wind energy potential is the energy available from the kinetic energy of the mass of the air moving in the wind.
5) Wind turbines are devices that can convert the wind kinetic energy into electric power.
6) A wind farm is a group of wind turbines on the same location used for the production of electricity.

7) Small scale wind power is the name given to wind generation systems with the capacity to produce up to 50 kW of electric power.

## 6. Wind Characteristics

The wind speed and its duration are the key factors that are considered in designing and determining the use of wind energy. The knowledge of monthly variation of wind speed provides confidence on the availability of energy in different months of the year. For Maiduguri, the monthly average wind speed derivable from Table 2.1 is presented in Table 6.1 and as box-whisker's plot in Fig. 6.1.

From this table, it is clear that wind is available throughout the year with a minimum value of 2.232 m/s in October and maximum of 4.136 m/s in June at anemometer height of 10 m.

**Table 6.1:** Monthly Average Sample Estimates of Wind Speed in Maiduguri

| Month | Average Speed (m/s) | S.E |
|---|---|---|
| January | 2.846 | 0.0365 |
| February | 3.123 | 0.0425 |
| March | 3.447 | 0.0397 |
| April | 3.540 | 0.0307 |
| May | 3.707 | 0.0374 |
| June | 4.136 | 0.0613 |
| July | 3.688 | 0.0615 |
| August | 2.874 | 0.0314 |
| September | 2.550 | 0.0288 |
| October | 2.232 | 0.0231 |
| November | 2.499 | 0.0355 |
| December | 2.425 | 0.0313 |

S E = Standard Error

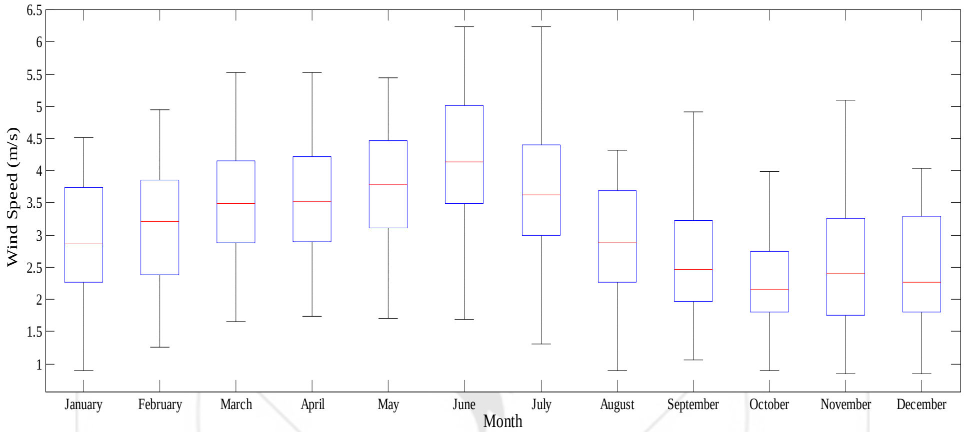


**Figure 6.1:** Box-Whiskers Plots for Monthly Wind Speed of Maiduguri

To determine the hub height at which a turbine of cut-in-speed of above 3 m/s can be placed, we use the expression [5]

$$V_2 = V_1 \left(\frac{h_2}{h_1}\right)^{\tau} \quad (2)$$

where $V_1$ is the known wind speed at a hub height of $h_1$, $V_2$ is the wind speed to be determined for a specified hub height $h_2$ and $\tau$ is the wind shear exponent. We assume $\tau$ = 1/7, which is the Wind Atlas Standard value [11], $V_1$ = 2.232, the minimum monthly average wind speed value for Maiduguri at $h_1$ = 10 m and calculate the wind speed at specified hub heights of $h_2$ = 140, 150, 160, 170, …, 200. These are tabulated in Table 7.1 below.

## 7. Wind Energy

The wind power, a measure of the energy available in wind, is given by

$$P_w = \frac{1}{2}\rho A V^3 \quad (3)$$

where $\rho$ is the air density taken as 1.225 kg/m$^3$, A is the cross section of the area through which it flows (swept area of turbine blade) in m$^2$ and V is the velocity of the wind. It is computationally easier to work with wind power density, which is simply given by

$$P = \frac{1}{2}\rho V^3 \quad (4)$$

From equations 3 and 4, it is clear that wind energy can be estimated directly from empirical data by using the sample mean value and from Weibull model mean value of wind speed, V. P in equation 4 gives the power available from the wind. Theoretically, only 59% of this power is extractable but practically it is only possible to extract 30% [12]. Hence, the practically extractable power is approximately [13] given by

$$P_E = 0.1V^3 \quad (5)$$

The monthly sample estimates of the power density at hub height 10 m for Maiduguri using equation 4 are presented in Fig 7.1 below.

From the Weibull wind model, the average wind power density is given by

$$P_w = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \quad (6)$$

where $c$ and $k$ are the scale and shape parameters of the Weibull distribution, respectively. For Maiduguri the estimates of these parameters have been obtained [7] and are here tabulated in Table 3.1. These estimates are used to compute the model estimates of wind power density shown in Fig. 7.1

From Table 6.1, it is clear that wind is available throughout the months of the year with a minimum of 2.232 m/s in October. The model mean of wind speed value obtained in October for hub height 10 m is used to compute the average wind speed at hub heights 140 m to 200 m, so as to determine the hub heights at which a turbine with a cut-in-speed of above 3 m/s can be accommodated. These are tabulated in Table 7.1 above. The corresponding practically extractable power is given in Table 7.2 for both the sample and model estimates.

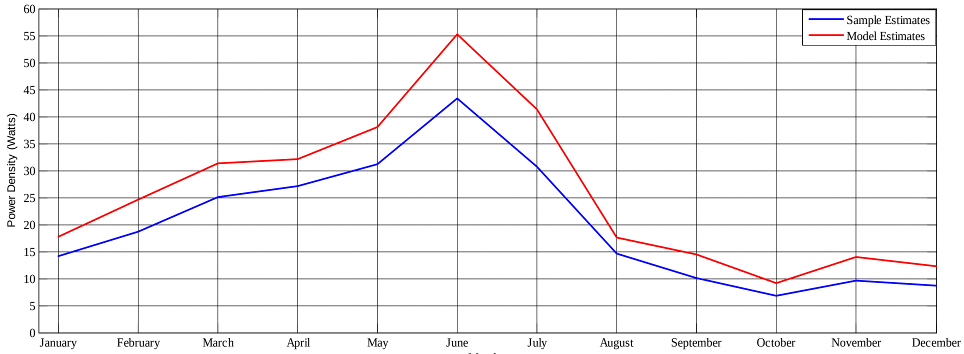


**Figure 7.1:** Sample and Model Wind Power Density Estimates for Maiduguri

**Table 7.1:** Estimated Average Wind Speed at Specified Hub Heights in Maiduguri

| Hub height (m) | 10 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|
| Sample Estimates (m/s) | 2.232 | 3.254 | 3.287 | 3.317 | 3.346 | 3.373 | 3.400 | 3.425 |
| Model Estimates (m/s) | 2.466 | 3.595 | 3.631 | 3.665 | 3.696 | 3.727 | 3.756 | 3.783 |

**Table 7.2:** Practically Extractable Power at Specified Hub Heights in Maiduguri

| Hub Height (m) | 10 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|
| Sample Estimate (W) | 1.112 | 3.446 | 3.551 | 3.650 | 3.746 | 3.838 | 3.930 | 4.018 |
| Model Estimate (W) | 1.500 | 4.646 | 4.787 | 4.923 | 5.049 | 5.177 | 5.299 | 5.414 |

## 8. Discussion of Results.

From Table 6.1, it is clear that wind is available throughout the year. From Table 7.1, the minimum wind speed obtained in October suggests that at hub heights of 140 m and above a turbine with a cut-in-speed of 3.2 m/s is feasible. Such turbine can be conveniently designed with a rated-speed of between 12-16 m/s and cut-out-speed of 17 m/s. This is because the range of values (see Fig 6.1) for the wind speed throughout the months of the year is nowhere near these values. The theoretically available power (Table 7.2), (at hub heights above 140 m) range above 3.45 W for sample estimates and 4.65 W for model estimates.

## 9. Conclusion

The analysis of wind speed data has clearly shown that wind energy has a great potential in Maiduguri. From the computation of the wind speed at hub heights in the range of 140 m to 200 m investigated, a wind turbine with a cut-in-speed of 3.2 m/s at 140 m hub height, which can generate 4.65 W of power (model estimates) is feasible.

It is a well known fact that wind energy derives from solar energy. This was easily noticed here as the monthly data on temperature is strongly positively correlated ($r = 0.613$, $p = 0.05$) with that of the monthly average wind speed. This implies that high values of temperature associate with high values of wind speed. Coupling a wind turbine of swept area of 11,000 $m^2$ into this environment can easily generate 51.2 kW of electricity for a small scale wind power. Twenty of these can form a modest wind farm that can generate 1 MW of electricity. Consequently, there is the possibility of generating higher wattage of electricity in areas of Borno State with higher average monthly temperature than Maiduguri. Northern Borno is a typical example.

Exploitation of wind energy potential is not yet popular with the Government. It is hoped that with the results of this research, government will begin to develop the impetus to look in this direction of alternative source of an eco-friendly electricity generation.

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