Estimation of wind energy potential of Benin City, Nigeria using data from two weather stations

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ABSTRACT

Lack of adequate supply of electricity is one of the major challenges faced by Nigeria. In this study, wind energy potential of Benin City, Nigeria was analyzed using wind data from two stations. Wind data for seven years (2009-2015) measured at the height of 10 m above the ground surface was obtained from the Nigeria Meteorological Agency (NIMET), Benin City. Wind speed data was similarly collected from National Centre for Energy and Environment (NCEE), located also in Benin City. The two sets of data followed the same seasonal pattern. The highest monthly average wind speed for the two stations occurred in the month of August with NIMET recording 1.40 m/s and NCEE having 1.46 m/s. The wind energy density using Weibull probability distribution shows that Benin City has the potential of generating a maximum monthly energy density of 2.62 KWh/m^2 based on the data from NIMET while the data from NCEE shows that a maximum monthly energy density of 3.63kWh/m^2 can be produced. The two sets of data provided opportunity for comparison and validation. The result obtained showed that Benin City has low wind profile which makes wind turbine commercially not viable.

KEYWORDS: average wind speed, energy density, NCEE, NIMET, wind energy.

1. INTRODUCTION

The importance of electric energy in our daily lives cannot be overemphasized. Many Nigerians have no stable supply of electricity despite its importance in the development of any nation. Provision of electricity is largely supplemented by the use of electricity generators powered by diesel or petrol. Over 70% of businesses in Nigeria have private electricity generators, leading to high production cost [1]. The power generated by Nigeria since the beginning of 2016 is less than 6000 MW for a population of over 170 million [2]. This is grossly inadequate as the energy per capital is approximately 35 Watts, which cannot even power an incandescent bulb. The growth of medium scale enterprises is one of the indices used for measuring the growth of an economy. Most of these enterprises primarily need electricity to operate. Hence, the need to look into other means of generating electricity other than the conventional use of fossil fuel. The use of renewable energy sources presents a solution to this problem. .

Renewable energy can be defined as energy gotten from sources that are naturally recreated. Renewable energy sources include solar, wind, hydro, biomass and geothermal. Apart from the fact that these sources can be replenished, they are also free from harmful emissions of green house gases. Wind energy is one the renewable energy that is yet to be given the required attention and fully harnessed in Nigeria. Today, wind energy is one of the fastest developing renewable energy technologies in the world. Wind is among the cheapest renewable energy sources per unit of electricity produced [3]. While countries have started to look at ways of harnessing this environmental friendly renewable resource, some others have already proved it and are extending their wind energy generation capacities [4]. In Africa, as at the end of 2015, South Africa tops the list with 1053 MW installed capacity, Morocco and Egypt occupying the second and third positions with 787 MW and 610 MW respectively [5].

Wind is an effect caused as a result of pressure differences over regions and heights in the atmosphere resulting in bulk motion of air masses. The force carried by the moving air mass (wind) can be harnessed for useful purposes such as grinding grain (in windmills) and generating electricity (in wind turbine generators). It is estimated that between 1.5 and 2.5% of the global solar radiation received on the surface of the earth is converted to wind. Hence, wind energy is a valuable alternative to the non-renewable and environmentally hazardous fossil fuels [6]. Wind energy has been widely used in Nigeria to power water supply for many decades now. In recent times efforts are largely geared towards its use for electricity generation, for example, the Federal Government of Nigeria is currently constructing 10 MW Wind Farm in Katsina and work has reached advanced stage of completion, although there are some issues with grid integration. In Nigeria, typical wind pattern occurs mostly from the east for inland areas and from the west over the coastal areas. During the harmattan period (December – March) strong winds appear covering the country especially in the northern parts [3]. The effective use of wind energy requires having a detailed knowledge of its potential at a location. Determining wind energy potential for a selected site is made by investigating detailed knowledge of wind characteristics, such as wind speed, direction and availability in that location [7]. In previous works, the wind energy potentials of different cities in Nigeria have been analyzed based on data from one weather station (in most cases from Nigeria Meteorological Agency). Obtaining data from one source does not provide opportunity for validation and comparison. In order to fill this research gap, this work analyses wind energy potential of Benin City, Nigeria using data from two different weather stations. The outcome of the research provided opportunity for comparison and validation of data.

2. THEORY

2.1 Average Wind Speed

The wind speed at a given location usually varies frequently under changing environmental conditions. Generally, wind assessment is based on average monthly wind speed because the wind has relatively homogeneous behavior within a month [8]. The average wind velocity (V_m) is among the most crucial information on the wind spectra of a location [9] (Mathew, 2006).

The average wind speed can be calculated using equation (1).

$$V_m = 1/n \sum_{i=1}^{n} Vi \qquad (1)$$

Where *Vi* is the *i*th wind speed (m/s) and *n* is the number of wind data.

2.2 Standard deviation

Standard deviation is a measure of unsteadiness of wind in an area. It can be calculated using equation (2)

$$\sigma_V = \sqrt{\frac{\sum_{i=1}^{n}(Vi-Vm)^2}{n}} \quad (2)$$

Where Vi = ith wind speed, Vm = average wind speed and n = number of wind data.

2.3 Wind speed frequency distribution

Frequency distribution of wind is important because it gives the range of wind speed that occurs the most.

2.4 Weibull wind speed distribution

The extent to which wind can be exploited as a source of energy depends on the probability density of occurrence of different speeds at the site, which is essentially, site-specific. To optimize the design of a wind energy conversion device, data on speed range over which the device must operate to maximize energy extraction is needed. This requires the knowledge of the frequency distribution of the wind speed. Among the probability density functions that have been proposed for wind speed frequency distributions of most locations, the Weibull distribution has been the most acceptable and forms the basis for commercial wind energy applications and software [6]. Weibull distribution is one of the accurate statistical models for describing wind frequency distribution. The use of this frequency approach can provide a simple model to predict the energy output of a wind energy conversion system [10]. In general, the wind speed Weibull distribution is characterized by two parameters, the scale parameter (C), and the shape parameter (K). The scale parameter C (in unit of m/s), is closely related to the wind speed of a location. The scale parameter shows how high the wind speed of a location is. The shape parameter, K which is dimensionless describes the width of the distribution and measures the probability of extraction of wind energy at a given characteristic wind speed [6]. The higher the K, the closer the speeds are to a particular value.

Weibull shape and scale parameters can be calculated using the energy pattern method as given in equations (3) and (4) [11].

$$K = 1 + \frac{3.69}{(E_{pf})^2} \quad (3)$$

$$C = \frac{V_m}{\Gamma(1+\frac{1}{k})} \quad (4)$$

Where V_m is the average wind speed, Γ is gamma function and E_{pf} is energy factor defined as given in equation (5)

$$E_{pf} = \frac{\frac{1}{n}\sum_{i=1}^{n} v_i^3}{(\frac{1}{n}\sum_{i=1}^{n} v_i)^3} \quad (5)$$

Where v_i is the wind speed.

The Weibull wind power density P(v) per unit area in W/m^2 can be obtained from equation (6)

$$P(v) = \frac{1}{2}\rho c^3(1+\frac{3}{k}) \quad (6)$$

Where ρ is the air density at the site which is taken as 1.225kg/m^3 [11].

3. METHODOLOGY

3.1 Data Acquisition

Wind speed data for seven years (2009-2015) measured at a height of 10 m above the ground were collected from Nigeria Meteorological Agency (NIMET), located at Benin Airport in Benin City. Wind speed data for five years (2011-2012) also measured at a height of 10 m was obtained from National Centre for Energy and Environment (NCEE) located at the University of Benin, Benin City.

3.2 Method used in measurement

The anemometer at NIMET is installed at a height of 10 m above the ground. It is connected to a "wind run" counter known as wind run recorder, which accumulates the wind run in kilometer (km). Wind run is a meteorological term used to determine the total distance travelled by wind over a period of time. A log book is used to enter the recorded wind run from 9:00hr to 9:00 hr the next day. The monthly average wind run (km) was converted to wind speed (m/s) using equation (7)

$$\text{Wind speed (m/s)} = \frac{wind\ run(km)}{86.4} \quad (7)$$

The anemometer at NCEE is also installed at a height of 10 m above the ground. The anemometer is connected to a data logger which is interfaced with a personal computer. A data logger is an electronic device that records measurement at set interval over a period of time. The wind speed data was assessed through the personal computer. The wind speed measuring system was installed in 2011. Therefore, the data covers from 2011 to 2015. The data logger records wind speed at 5 minutes interval. The 5 minutes interval wind speed was converted to monthly wind speed by taking their averages.

4. RESULT AND DISCUSSIONS

Table 1. Monthly average wind speed for Benin City from NIMET (2009-2015)

Month	WIND SPEED(m/s)							
	2009	2010	2011	2012	2013	2014	2015	AVERAGE
Jan.	XX	1.03	1.08	1.09	1.14	1.18	1.41	**1.16**
Feb.	XX	1.32	1.44	1.20	1.33	1.10	1.35	**1.29**
Mar.	XX	1.10	1.40	1.41	1.40	1.21	1.05	**1.26**
Apr.	XX	1.32	1.12	1.32	1.18	1.18	0.78	**1.15**

May	XX	1.14	1.16	1.13	1.16	1.04	1.13	**1.13**
Jun.	0.76	1.10	1.10	1.12	1.16	1.05	1.01	**1.04**
Jul.	1.28	1.14	1.18	1.20	1.20	1.09	1.18	**1.18**
Aug.	1.55	1.22	1.37	1.58	1.45	1.33	1.29	**1.40**
Sep.	1.21	1.15	1.23	1.10	XX	1.11	1.16	**1.16**
Oct.	0.96	0.71	0.90	0.80	1.07	0.90	0.84	**0.88**
Nov.	0.80	0.54	0.81	0.83	0.94	0.79	0.77	**0.78**
Dec.	0.80	0.74	1.07	0.75	1.02	0.73	0.85	**0.85**
							AVERAGE	**1.11**

Table 2. Monthly average wind speed of Benin City from NCEE (2011-2015)

MONTH	**WIND SPEED(m/s)**					
	2011	**2012**	**2013**	**2014**	**2015**	**AVERAGE**
Jan.	XX	1.57	1.39	0.81	0.89	**1.17**
Feb.	XX	2.12	1.37	0.97	0.92	**1.35**
Mar.	XX	1.76	1.67	0.89	0.71	**1.26**
Apr.	XX	1.79	1.24	XX	0.59	**1.21**
May.	XX	1.56	1.23	0.74	0.75	**1.07**
Jun.	XX	1.55	1.32	0.62	0.98	**1.12**
Jul.	XX	1.81	1.57	0.97	1.03	**1.35**
Aug.	1.77	2.08	1.39	1.14	0.94	**1.46**
Sep.	1.77	1.73	0.90	0.93	0.82	**1.23**
Oct.	1.30	1.23	0.66	0.59	0.45	**0.85**
Nov.	1.20	0.85	0.62	0.48	XX	**0.79**
Dec.	1.59	1.03	0.72	0.51	0.32	**0.83**
					AVERAGE	**1.14**

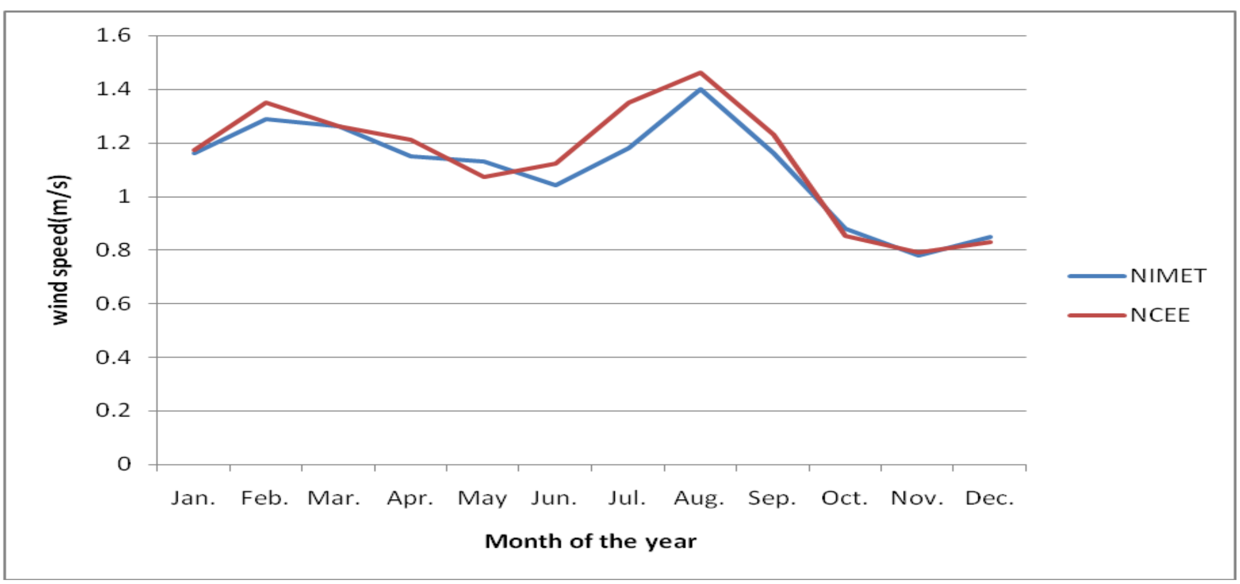

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Figure 1. Variation in monthly average wind speed for Benin City.

Table 3. Wind speed frequency distribution from NIMET and NCEE.

Wind speed range	NIMET		NCEE	
	Frequency of occurrence	Percentage	Frequency of occurrence	Percentage
0.32-0.61	1	1.3	6	11.8
0.62-0.91	17	21.8	13	25.5
0.92-1.21	41	52.6	9	17.7
1.22-1.51	17	21.8	9	17.7
1.52-1.81	2	2.6	12	23.5
1.82-2.11	0	0	1	2
2.12-2.41	0	0	1	2

Table 4. Standard deviation of average monthly wind speed from NIMET and NCEE.

MONTH	NIMET		NCEE	
	Average wind speed(m/s)	Standard deviation	Average wind speed(m/s)	Standard deviation
Jan.	1.16	0.123	1.17	0.323
Feb.	1.29	0.110	1.35	0.480
Mar.	1.26	0.149	1.26	0.463
Apr.	1.15	0.181	1.21	0.491
May	1.13	0.041	1.07	0.345
Jun.	1.04	0.124	1.12	0.352
Jul.	1.18	0.054	1.35	0.356
Aug.	1.40	0.124	1.46	0.414
Sep.	1.16	0.047	1.23	0.426
Oct.	0.88	0.107	0.85	0.349
Nov.	0.78	0.112	0.79	0.272
Dec.	0.85	0.129	0.83	0.446

Table 5. Monthly average Power and Energy Density for Benin City based on data from NIMET and NCEE

MONTH	NIMET					NCEE				
	Average wind speed(m/s)	K	C	Power Density (W/m^2)	Energy Density (KWh/m^2)	Average wind speed(m/s)	K	C	Power Density (W/m^2)	Energy Density (KWh/m^2)
Jan.	1.16	4.51	1.27	2.09	1.51	1.17	3.49	1.30	2.50	1.80

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Feb.	1.29	4.61	1.41	2.83	2.04	1.35	2.88	1.51	4.31	3.10
Mar.	1.26	4.37	1.38	2.72	1.96	1.26	2.89	1.41	3.50	2.52
Apr.	1.15	4.22	1.27	2.14	1.54	1.21	2.69	1.36	3.26	2.35
May	1.13	4.73	1.24	1.91	1.38	1.07	3.11	1.20	2.08	1.50
Jun.	1.04	4.36	1.14	1.53	1.10	1.12	3.25	1.25	2.30	1.66
Jul.	1.18	4.62	1.29	2.17	1.56	1.35	3.56	1.50	3.81	2.74
Aug.	1.40	4.54	1.53	3.64	2.62	1.46	3.34	1.63	5.04	3.63
Sep.	1.16	4.65	1.27	2.06	1.48	1.23	2.95	1.38	3.25	2.34
Oct.	0.88	4.31	0.97	0.95	0.68	0.85	2.61	0.96	1.17	0.84
Nov.	0.78	4.23	0.85	0.64	0.46	0.79	2.98	0.88	0.84	0.61
Dec.	0.85	4.18	0.94	0.87	0.63	0.83	1.95	0.94	1.29	0.93

The cells with XX in Table 1 and Table 2 indicate months when measurements were not taken due to faulty measuring instrument.

The result shows that the wind speed data from the two stations are similar and also follow the same seasonal pattern as shown by the graph in figure 1. The two sets of data as given in Table 1 and Table 2 showed that the highest monthly average wind speed occurred in the month of August with NIMET recording 1.4m/s and NCEE having 1.46m/s. The lowest monthly average wind speed occurred for the two data in November with NIMET and NCEE recording 0.78m/s and 0.79m/s respectively.

Table 3. Shows that the dominant average monthly wind speed for NIMET falls between 0.92 and 1.21 m/s and that of NCEE falls between 0.62 and 0.91 m/s. The monthly standard deviation for NIMET is lowest in the month of May and highest in April as shown in Table 4. This indicates that the month of May has the most steady wind profile while April is the most turbulent. For the case of NCEE, it recorded its lowest deviation in November and highest in April. The overall standard deviation of wind speed for NCEE is relatively larger than that for NIMET, which suggests that the wind profile at NIMET is less turbulent than that at NCEE.

Table 5 shows that the Weibull K parameter for NIMET is higher than that of NCEE, which indicates that the monthly average wind speed for NIMET are closer to a particular value, while that of NCEE are relatively more dispersed. The Weibull C parameter for NCEE is higher than that of NIMET which indicate that NCEE has higher wind speed than NIMET. Based on the data from NIMET, Benin City has the potential of generating a maximum monthly average power density and energy density of $3.64W/m^2$ and $2.62KWh/m^2$ respectively (in August) as shown in Table 6. While the data from NCEE shows that a maximum monthly average power density and energy density of

5.04W/m^2 and 3.63kWh/m^2 respectively can be produced as also given in Table 6.

Comparison between satellite data and ground station data

Table 5 presents the average monthly wind speed of Benin City(obtained from NIMET and NCEE) measured through a ground station being compared with the average monthly wind speed of Benin City obtained through satellite from the National Aeronautics and Space Administration ((NASA) [12]. It can be observed that the average monthly wind speed recorded by the satellite is higher than the ones recorded by the ground stations, although wind speed measured through ground station are more reliable. It was also observed that they follow almost the same seasonal pattern.

Table 6. Average monthly wind speed comparison between satellite and ground station measurement

Month	NASA Average wind speed(m/s)	NIMET Average Wind speed(m/s)	NCEE Average Wind speed(m/s)
Jan.	2.31	1.16	1.17
Feb.	2.52	1.29	1.35
Mar.	2.43	1.26	1.26
Apr.	2.22	1.15	1.21
May	1.94	1.13	1.07
Jun.	2.13	1.04	1.12
Jul.	2.31	1.18	1.35
Aug.	2.39	1.40	1.46
Sep.	2.17	1.16	1.23
Oct.	1.90	0.88	0.85
Nov.	1.96	0.78	0.79
Dec.	2.11	0.85	0.83
Average	**2.19**	**1.11**	**1.14**

5. CONCLUSION

In this work, the wind energy potential of Benin City, Nigeria has been determined based on wind speed data from two stations. It has provided an avenue for validation and comparison of the data from both stations. The data obtained from the two stations are similar. The little difference in the wind speed data from the stations could be as a result of difference in the surrounding features such as trees and tall buildings around the two locations. Considering the result obtained, commercial wind turbine is not viable in Benin City due to its low wind profile. However, it may be suitable for micro wind turbines for charging of batteries. This work can assist government or any other relevant organizations make informed decision with regard to investment in wind power in Benin City.

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