International Journal of Energy and Power Engineering
2013; 2(5): 184-190
Published online October 20, 2013 (http://www.sciencepublishinggroup.com/j/ijepe)
doi: 10.11648/j.ijepe.20130205.11

An investigation of wind characteristics and techno-economic evaluation of wind energy in Nigeria

A. Ahmed[1], A. A. Bello[2], D. Habou[2]

[1]Department of Mechanical Engineering, Kano University of Science and Technology, Wudil
[2]Department of Mechanical Engineering, Abubakar Tafawa Balewa University, Bauchi

Email address:
abdula2k2@yahoo.com (A. Ahmed), biieeyz@yahoo.com (A. A. Bello), hdandakuta@gmail.com (D. Habou)

To cite this article:
A. Ahmed, A. A. Bello, D. Habou. An Investigation of Wind Characteristics and Techno-Economic Evaluation of Wind Energy in Nigeria. *International Journal of Energy and Power Engineering.* Vol. 2, No. 5, 2013, pp. 184-190. doi: 10.11648/j.ijepe.20130205.11

Abstract: In this study, wind characteristics and techno-economic analysis in six selected locations in the northern (Jos, Kano, Sokoto and Maiduguri) and southern (Lagos and Enugu) regions of Nigeria using wind speed data at 10m height collected over a period of seventeen years (1990-2006) were analyzed. The techno-economic evaluations of electricity generation from four commercial wind turbine models used for electricity generation located at these sites were evaluated. The wind speed data analysis shows that the sites evaluated are good locations for wind potential in electricity generation from wind. The yearly energy output, the capacity factor and the wind energy cost per unit of electricity generated by the selected wind turbines are calculated. In terms of energy production, the results show that Plateau is best location for harnessing wind power for electricity generation with an average wind power density of 713.95W/m^2. The maximum energy output was obtained for De wind 48 turbine model. The capacity factor values are found to vary from a minimum of 21% to maximum of 28% for this research work. The results also shows that the cost per kWh of electricity generation using these turbines is between 0.493 – 0.606$kWh.

Keywords: Wind Energy, Weibull Parameters, Capacity Factor, Energy Production

1. Introduction

Wind energy has been used since the earliest civilization to grind grain, pump water from deep well and power sailboats. With the recent surge in fossil fuel prices, demand for cleaner energy sources, and government funding incentives, wind turbines have become viable technology for power generation, because the utilization of wind energy has been increasing around the world at an accelerating pace. Wind turbines represent a developing and promising technology for power production without air pollution [1]. Wind data analysis are needed in many parts of the world to enable governments, private developers and others to determine the priority that should be given to wind energy utilization and to identify potential areas that might be suitable for development. The distribution of wind speed is important for the design of wind farms, power generators and agricultural applications such as the irrigation [2]. Today, wind analysis provides remarkable information to researchers and designers that are involved in renewable energy studies.

Nigeria can reduce its level of dependency on fossil fuel by making use wind energy which is an indigenous renewable energy source for electricity generation. Wind energy has been recognized as one of the most promising renewable energy source because of the long term sustainable energy supply, also serve as a source of clean energy. Wind energy has also been identified as an inexpensive alternative energy source, because during the 1980’s, the cost of wind generated electricity dropped from about 15-20 cents/kWh (EC, 2007) to a current average cost of 3-7cents/kWh [3]. However, the major factor in the reduction of the cost over the last 20 years has been the increase size of individual wind turbines and wind farm projects together with engineering and design improvements to the blades, electronic controls and weight reduction of individual components that impacts their manufactured costs [3].

In the last decade, a lot of studies related to the wind characteristics and wind power potential have been developed in many countries worldwide by researchers, due to the need of a balance between energy security, economic development and protection of the environment.

Ucar and Balo (2009) worked on technical and economic assessment in Uludag-Bursa, Turkey for electricity generation from wind turbines. From the study, the cost of each kWh produced using the chosen wind turbines in Uludag-Bursa were found to be between 0.255 and 0.306$/kWh.

Adaramola et al (2012) studied the techno-economic analysis of wind energy in southwest Nigeria. In his study, the results shows that electricity cost varied from 0.06997 and 0.11195$(kW.h) to 2.86611 and 4.58578$(kW.h) at limit values of turbine specific cost band intervals of 1000 and 1600$/kW.

Durisic and Mikulovic (2012) worked on wind energy resources in the south Banat region. The data were collected at height of 10, 40, 50 and 60m during 2009 and 2010. The results shows that the region of south Banat possesses good wind energy potential and quite promising for development of wind farms.

Diaf and Notton (2013) studied the wind energy potential and economic analysis in 13 locations in Algeria were investigated using wind speed data measured at 10m height. The capacity factors for the locations were computed to be between 6–48%. Based on the obtained results, the wind resource appears to be suitable for power production in the southern region of Algeria.

In this study, the wind characteristics and techno-economic evaluation of wind energy for six locations situated in different parts of Nigeria were analyzed using the wind speed data collected at10m height for the period (1990-2006). This study provides information for developing a wind energy potential sites and economic analysis for commercial wind turbines for the locations.

2. Wind Speed Data Collection

The wind speed data were collected for the period (1990-2006) from Nigerian meteorological station, Abuja at 10m height for six different sites located in the northern and southern parts of Nigeria. Table 1 shows the geographical data for the selected locations in this study.

Table 1. *Geographical data for the selected locations*

LOCATIONS	STATE	LATITUDE (N)	LONGITUDE (E)	ALTITUDE (M)	ALTITUDE (FT)
Kano	Kano	$11^0$59'47	$8^0$31'0	476	1564
Sokoto	Sokoto	$13^0$3'5	$5^0$13'45	272	895
Maiduguri	Borno	$11^0$50'47	$13^0$9'37	299	984
Jos	Plateau	$9^0$55'0	$8^0$54'	1217	3996
Lagos	Lagos	$6^0$27'11	$3^0$23'45	34	114
Enugu	Enugu	$6^0$26'25	$7^0$29'39	247	813

Source: http://www.fallingrain.com

2.1. Weibull and Rayleigh Distribution of Wind Speed

Evaluation of wind speed potential in a windy area is very important using the knowledge of wind speed frequency distribution. If the wind speed distribution in any windy site is known, the power potential and the economic feasibility belonging to the site can easily be obtained. Wind data with various observation methods has wide ranges. Therefore, in the wind energy analysis, it is necessary to have only few parameters that can explain the behavior of a wide range of wind speed data. The simplest and most practical method for the procedure is to use a distribution function. There are several density functions, which can be used to describe the wind speed frequency curve. The most common of two are the Weibull and Rayleigh models [4].

The Weibull distribution method is widely accepted for evaluating local wind load probabilities and is considered as a standard approach. This method has a great flexibility and simplicity. However, the main limitation of the Weibull density function is its inability to accurately calculate the probabilities of observing zero or very low wind velocities. Weibull parameter distribution function does not address the differences of wind velocity variation during the course of a day. Nevertheless, this statistical method is found to fit a wide collection of recorded wind data. The Weibull distribution is often used in the field of life data analysis due to its flexibility; it can mimic the behavior of the other statistical distributions such as the normal and exponential. The general form of the Weibull distribution for the wind speed is given by [4];

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

where v is the wind speed, c is the Weibull scale factor and k is a dimensionless Weibull shape parameter. The cumulative probability function of Weibull distribution is given as;

$$F_W = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (2)$$

F_W = Weibull cumulative distribution function

For the purpose of estimating the parameters of Weibull distribution k and c, the following equations are used;

$$k = \left(\frac{\sigma}{v_m}\right)^{-1.086} \tag{3}$$

$$c = v_m \left(\frac{k^{2.6674}}{0.184 + \left(0.816 k^{2.73859}\right)}\right) \tag{4}$$

Another distribution function used to the wind speed frequency is Rayleigh distribution. This distribution is a special case of the Weibull distribution in which the shape factor is 2. Probability density and cumulative function of Rayleigh distribution are calculated as [4];

$$f_R(v) = \frac{\pi}{2}\frac{v}{v_m^{\,2}} \exp\left[-\left(\frac{\pi}{4}\right)\left(\frac{v}{v_m^{\,2}}\right)^k\right] \tag{5}$$

$$F_R(v) = 1 - \exp\left[-\left(\frac{\pi}{4}\right)\left(\frac{v}{v_m}\right)^2\right] \tag{6}$$

where

$f_R(v)$ = Rayleigh probability density function
$F_R(v)$ = Rayleigh cumulative distribution function

2.2. Wind power density

The wind resource at a location can be roughly described by the mean wind speed, but the wind power density provides a truer indication of a site's wind energy potential. The power density is proportional to the sum of the cube of the instantaneous wind speed and the air density. Due to this cube term, two locations with the same average wind speed but different distributions can have different wind power density values. The power density of the wind can be estimated by using following equation;

$$P(v) = \frac{1}{2}\rho A v^3 \tag{7}$$

where A is swept area (m^2), ρ is air density (kg/m^3)

3. Economics Analysis

The capacity factor C_f is one of the performance parameters of wind turbines which both the user and manufacturer need to know. It represents the fraction of the total energy delivered over a period, E_{out}, divided by the maximum energy that could have been delivered if the turbine was used at maximum capacity over the entire period E_r=8760Pr. The capacity factor C_f of a wind turbine can be calculated as [2]

$$C_f = \frac{E_{out}}{E_r} \tag{8}$$

where E_{out} is energy output (kWh/year), C_f is capacity factor, E_r is maximum energy capacity, P_r is rated power.

In this study, the following assumptions are used to determine the present value of costs of electricity:

(a) Investment (*I*) includes the turbine price plus its 20% for the civil work and other connections.
(b) Operation maintenance and repair cost (C_{omr}) was considered to be 25% of the annual cost of the turbine (machine price/lifetime).
(c) The life time of the machine (*t*) was assumed to be 20years.
(d) The interest rate (*r*) and inflation rate (*i*) were taken to be 15% and 12%, respectively.
(e) Scrap value *S* was taken to be 10% of the turbine price and civil work.

3.1. Cost Analysis

The economic viability of the wind energy projects depends on its ability to generate electricity at a low operating cost per unit energy, an accurate estimation of all the costs occurring over the life span of the system, is essential. Different methods are generally used to estimate the operating cost of a unit energy produced by the wind energy conversion system [5].

In this study, the estimation of the cost per unit is made by estimating the specific cost per kilowatt hour, which is expressed as the ratio of accumulated net present value of all the costs, PVC, to the total energy produced by the system during the wind turbine lifetime.

The present value of cost (*PVC*) is;

$$PVC = 1 + C_{omr}\left[\frac{1+i}{r-i}\right] * \left[1 - \left(\frac{1+i}{1+r}\right)^t\right] - S\left(\frac{1+i}{1+r}\right)^t \tag{9}$$

where C_{omr} is operation, maintenance and repair cost, i is inflation rate, r interest rate (%), t is lifetime of the machine (year), S is scrap value

The determination of the unit cost of energy involves two main steps: In the first step, the PVC is calculated from equation (9) by taking into considerations the initial investment cost of the system and the present value of operation and maintenance cost throughout the lifetime system. The second step consists to determine the unit cost per kWh.

4. Results and Discussion

The analysis of the wind characteristics at 10m height in Nigeria for the period of (1990 – 2006) have been used to achieve the wind power density and techno – economic evaluation of the wind energy in Nigeria. The cumulative frequency distribution of wind speed, monthly wind speed, Weibull parameter (*c* and *k*), capacity factor and present value cost of the selected wind turbine has been carried out. Figure 1, shows histogram of the cumulative frequency distribution of the wind speed for the period considered (1990-2006) at 10m height at the following locations; Kano

(North West), Sokoto (North West), Jos (North Central), Maiduguri (North East), Lagos (South West) and Enugu (South East) of Nigeria.

Tables 2 - 5 present the basic information of the wind energy resources in the locations considered in this research. From the tables, the values of (c and k) vary from 4.33 – 12.63m/s and 2.43 – 16.59 respectively. It can be seen from the tables that the power density varies from 44 – 1219W/m^2. It can be observed that the northern region of Nigeria have high wind energy potential than the southern region of Nigeria.

Figure 2, shows average wind speed month by month for all the locations considered over the period (1990-2006). It can be seen from the graph that the lowest monthly average wind speed is 3.85m/s in November at Lagos (South West) and the highest wind speed is 11.74m/s in February at Jos (North Central).

Figure 3, shows average monthly wind power density for the locations considered in this research. It was observed that low power density occurred from October to December in Maiduguri (North East), Lagos (South West) and Enugu (South East), while from January to September, high wind power density was observed which is above 100W/m^2. It can be seen from the graph that locations like Kano (North West), Sokoto (North West) and Jos (North Central) have high wind power density ranging from 100W/m^2 – 1219W/m^2 all through the months.

From the monthly average wind speed and power density, all the locations considered in this research have the potential of electricity generation in Nigeria, since almost all the locations have monthly average power density above 100W/m^2.

Table 2. *Average wind speed (m/s) data at 10m height for the viable locations for electricity generation in Nigeria.*

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kano	8.99	9.28	9.29	9.15	10.16	10.86	9.21	7.79	7.82	6.94	7.15	8.19
Sokoto	7.99	7.88	7.54	7.31	8.65	8.92	7.65	5.85	5.12	5.21	6.22	7.21
Jos	11.37	11.74	10.47	10.96	10.32	10.07	9.64	8.85	8.35	8.25	10.31	11.6
Maiduguri	4.94	5.85	6.27	6.02	6.27	6.88	6.19	5.03	4.33	4.07	4.52	5.06
Lagos	4.76	5.70	6.18	5.92	5.31	4.99	6.32	6.44	5.49	4.25	3.85	4.75
Enugu	5.92	5.68	6.14	6.47	5.54	5.34	5.71	5.34	5.14	4.56	4.42	5.34

Source: Nigerian Meteorological Station (NIMET), Abuja

Table 3. *The results for the Weibull scale factor c (m/s) for the locations in Nigeria.*

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kano	9.66	10.16	10.01	9.72	10.76	11.24	9.77	8.28	8.35	7.34	7.82	8.99
Sokoto	8.51	8.74	8.20	8.01	9.07	9.32	8.17	6.19	5.54	5.70	6.95	7.92
Jos	12.16	12.63	11.11	11.37	10.77	10.6	10.02	9.77	8.86	8.91	10.95	11.9
Maiduguri	5.45	6.48	6.79	6.42	6.71	7.24	6.68	5.42	4.71	4.43	4.87	5.59
Lagos	5.24	6.28	6.80	6.54	5.92	5.49	7.01	7.20	6.09	4.70	4.33	5.27
Enugu	6.68	6.28	6.72	6.72	5.76	5.42	5.74	5.96	5.20	4.57	4.69	5.92

Table 4. *The results for the Weibull shape factor (k) for the locations in Nigeria.*

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kano	6.26	4.70	5.34	7.38	7.26	10.68	7.51	7.39	6.76	7.72	4.74	4.45
Sokoto	7.15	3.76	5.20	4.55	8.86	9.27	6.81	7.67	5.70	4.72	3.30	5.24
Jos	6.74	6.11	7.50	10.32	9.44	8.37	10.11	4.07	7.49	5.74	7.32	6.45
Maiduguri	4.11	3.81	5.53	6.85	6.65	6.91	5.81	5.92	5.06	5.03	5.90	4.11
Lagos	4.36	4.24	4.19	4.09	3.28	4.28	3.77	3.21	3.66	4.04	2.72	3.67
Enugu	2.43	4.01	4.65	10.26	9.98	14.31	15.81	3.18	14.71	16.59	7.37	3.78

Table 5. *Average power density in (W/m^2) for the viable locations in Nigeria.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kano	508	582	570	1219	709	823	491	362	362	222	254	402
Sokoto	350	367	299	292	424	424	298	140	95	105	210	286
Jos	989	1056	751	856	675	647	566	487	368	481	728	964
Maiduguri	85	148	164	146	175	208	158	87	54	46	62	113
Lagos	85	89	168	145	135	99	205	218	137	54	44	56
Enugu	142	122	164	162	100	100	67	121	85	59	53	98

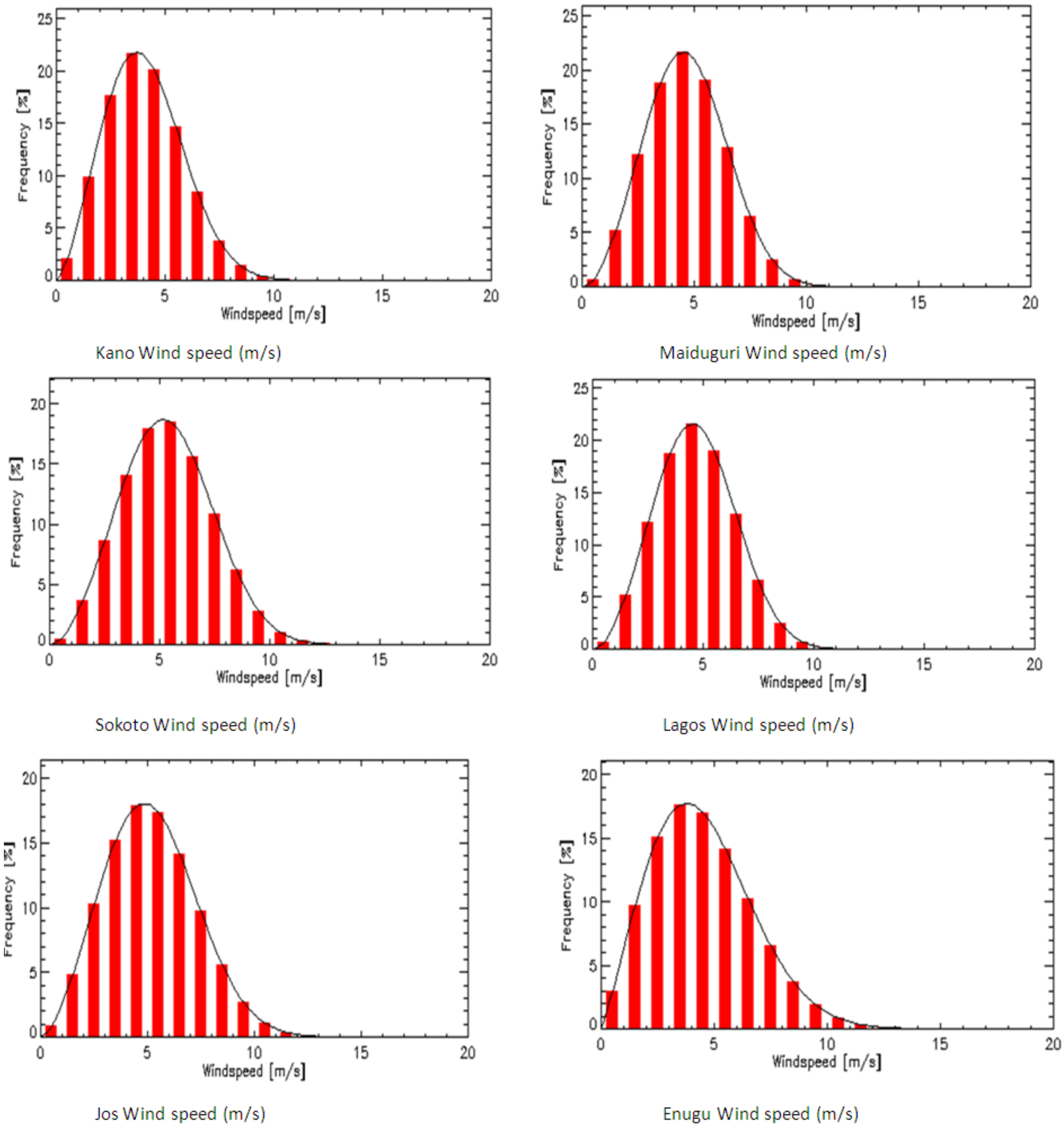

Fig 1. *Histograms of wind speed compared to Weibull distributions for wind potential regions in Nigeria.*

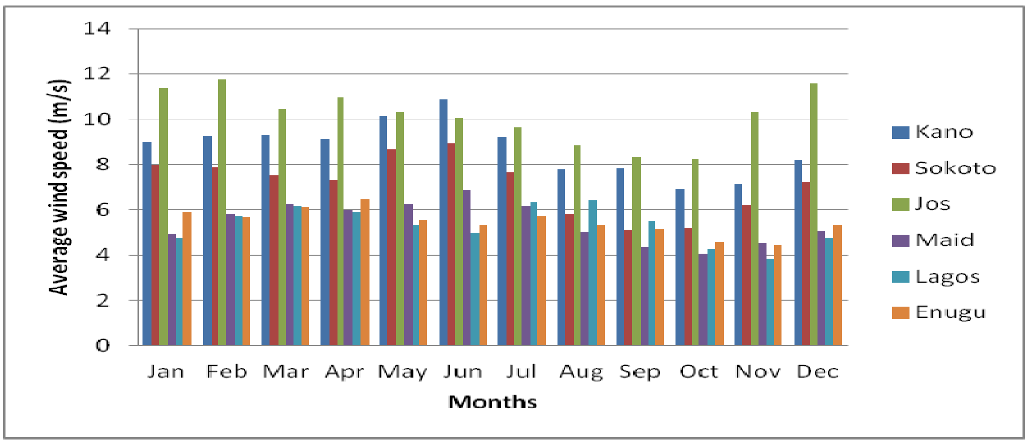

Fig 2. *Average monthly wind speed at different locations in Nigeria over the period (1990 – 2006).*

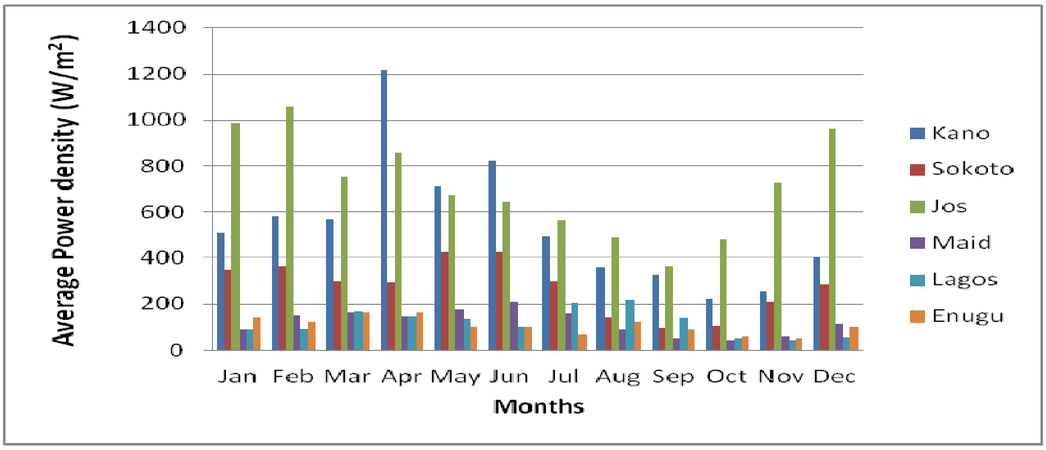

Fig 3. *Average monthly power density at different locations in Nigeria over the period (1990 – 2006)*

4.1. Wind Turbine Energy Production

For the purpose of verifying the wind potential at the targeted locations, calculation of annual electricity production (AEP) and the corresponding capacity factor (CF) for the four wind turbine models has been carried out. The calculations are performed for four different hub heights 40m, 65m, 70m and 80m. The characteristics properties of the selected wind turbine are presented in table 6.

Table 6. *Commercial wind turbine characteristics*

Characteristics	**De Wind 48**	**De Wind D6**	**De Wind D7**	**De Wind D8**
Hub height (m)	40	65	70	80
Rated power Pr (kW)	600	1250	1500	2000
Swept area (m^2)	1808	3019	3846	5027
Cut-in wind speed V_{ci} (m/s)	2.5	2.8	3	3
Rated wind speed V_r (m/s)	11.5	12.5	12	13.5
Cut-off wind speed V_{co} (m/s)	25	25	25	25
Price ($)	530,000	1,065,000	1,338,000	1,800,000

Table 7. *Yearly gain, Capacity factor and cost for commercial wind turbines.*

Turbine model	**Rated power Pr (kW)**	**Energy output E_{out} (kWh/year)**	**Capacity factor C_r (%)**	**PVC ($)**	**Cost ($/kWh)**
De Wind 48	600	1,181,638	23	700,072.3	0.593
De Wind D6	1250	2,323,047	21	1,406,756.6	0.606
De Wind D7	1500	3,077,284	23	1,767,351.5	0.574
De Wind D8	2000	4,823,243	28	2,377,602.9	0.493

The PVC for each turbine is calculated by substituting technical data of the chosen wind turbines in Eq. (9). The cost of electricity per kWh for each wind turbine is obtained by dividing the PVC by the total energy production of the wind turbine over its lifetime (20 years) and it is seen in Table 7. The cost of electricity produced from wind turbine of different capacity is shown in Table 7.

5. Conclusion

In this study, the monthly and yearly wind speed distribution and wind power density during the period (1990-2006) in Nigeria were used to evaluate the wind power density and techno-economic analysis of the wind energy. The wind speed frequency distribution of the locations was found by using Weibull parameters (*c* and *k*). It can be concluded as follows:

1) The highest monthly mean wind speed is determined as 11.74m/s in February at Jos while the lowest mean wind speed 3.85m/s occurred in November at Lagos.
2) The lowest wind power occurred in Lagos with value of 44W/m^2 in month of November while highest wind power density as 1219W/m^2 in Kano in the month of April.

3) The value of (*c* and *k*) for the whole locations varies from 4.43 – 12.63m/s and 2.43 – 16.59 respectively.
4) The graphs of wind speed and percentage frequency shows almost the same trend with a pronounced peak in each case, this shows a good indication for electrical energy production in those locations.
5) The Weibull distribution describes very well the frequency distribution of the wind speed in all the location considered in this study. The northern region is characterized by a strong wind speed increment with height and it is economically feasible to use high wind turbines masts in these locations.
6) It was obtained that the expected cost of each kWh produced using the chosen wind turbine 600, 1250, 1500 and 2000 kW are 0.593,0.606,0.574 and 0.493$/kWh in Nigeria for years (1990-2006), respectively.
7) The electricity generation cost per kWh from wind machines in almost all the locations has a very competitive price as shown in table 7.

References

[1] Maatallah T, El Alimi S, Dahmouni AW, Ben Nasrallah S. Wind power assessment and evaluation of electricity generation in the Gulf of Tunis, Tunisia. Sustainable Cities and Society 2013; 6: 1-10.

[2] Ucar A, Balo F. Investigation of wind characteristics and assessment of wind-generation potentiality in Uludag- Bursa, Turkey. Applied Energy 2009; 86: 333-339.

[3] Balat M. A review of modern wind turbine. Energy Sources 2009; 31(17):1561-1572.

[4] Ahmed A, Bello AA, Dandakouta H. An evaluation of wind energy potential in the northern and southern regions of Nigeria on the basis of Weibull and Rayleigh models. American Journal of Energy Engineering 2013; 3: 37- 42.

[5] Diaf S, Notton G. Evaluation of electricity generation and energy cost of wind energy conversion systems in southern Algeria. Renewable and Sustainable Energy Reviews 2013; 23: 379-390.

[6] Gass V, Schmidt J, Strauss F, Schmid E. Assessing the economic of wind power potential in Austria. Energy Policy 2013; 53: 323-330.

[7] Adaramola MS, Paul SS, Oyedepo SO. Assessment of electricity generation and energy cost of wind energy conversion systems in north-central Nigeria. Energy Conversion and Management, 2011, 52 (12): 3363-3368.

[8] Adaramola MS, Oyewola MO, Ohunakin OS, Dinrifo RR. Techno-economic evaluation of wind energy inn southwest Nigeria. Front Energy, 2012, 6 (4): 366-378.

[9] Sedaghat A, Mirhosseini M. Aerodynamic design of a 300kW horizontal axis wind turbine for province of Semnan. Energy Conversion and Management 2012; 63: 87-94.

[10] Diaf S, Notton G. Technical and economic analysis of large-scale wind energy conversion systems in Algeria. Renewable and Sustainable Energy Reviews 2013; 19: 37-51.

[11] Felix AA, Akinbulire TO, Abdulkareem A, Awosope COA. Wind energy potential in Nigeria. International Electrical Engineering Journal 2012; 3(1): 595-601.

[12] Emani N, Behbani-Nia A. The statistical evaluation of wind speed and power density in the Firouzkouh region in Iran. Energy Sources 2012; 34(12): 1076-1083.

[13] Durisic Z, Mikulovic J. Assessment of the wind energy resources in the south Banat region, Serbia Renewable and Sustainable Energy Reviews 2012; 16: 3014-3023.

[14] Ulgen K, Hepbasli A. Determination of Weibull parameter for wind energy analysis of Izmir, Turkey. International Journal of Energy Research 2002; 26:495-506.

[15] Wu J, Wang J, Chi D. Wind energy potential assessment for the site of Inner Mongolia in China. Renewable and Sustainable Energy Reviews 2013; 21: 215-228.