
An evaluation of wind energy potential in the northern and southern regions of Nigeria on the basis of Weibull and Rayleigh models

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Abstract: This paper presents an evaluation of wind energy potential in the northern and southern region of Nigeria on the basis of Weibull and Rayleigh models. The aim of this study is to know which of the locations in the regions would have more wind power density where wind energy conversion system (WECS) could be installed for electricity generation in Nigeria with excellent percentage of clean energy. From the analysis of the wind speed data collected from Nigeria meteorological station, Abuja at 10m height from years (1990 – 2006) the locations in northern region of Nigeria that were found quite viable for electricity generation are (Jos, Kano, Sokoto and Maiduguri) while for the southern region of Nigeria are (Lagos and Enugu). These locations were found to have wind power density above 100W/m². The Weibull model was found to be more applicable in estimating the power density because it returns a lower percentage error than the Rayleigh model. Probability density function in the northern region has a peak value of 1.01795 and 0.2937 in Bauchi for both Weibull and Rayleigh respectively while for the southern region the probability density function has a peak value for Weibull as 0.8347 in Calabar and Rayleigh as 0.2341 in Rivers southern region of Nigeria.

Keywords: Wind Energy Potential, Nigeria, Generation, Weibull, Rayleigh, Probability Density Function

1. Introduction

Wind energy is a free, clean and inexhaustible energy source. It has served mankind for many centuries by propelling ships and driving wind turbines to grind grains and pump water. Wind power and other forms of solar power are being strongly encouraged. Wind power may become a major source of energy in spite of slightly higher costs than other traditional sources of energy generation. Considerable progress is being made in making wind power less expensive, but even without a clear cost advantage, wind power will become important in the world energy sources. Wind energy is the world's fastest growing energy source and it can power industry, businesses and homes with clean, renewable electricity for many years to come. Wind turbines do not consume fuel due to its operation. It does not produce emissions such as carbon dioxide, sulphur dioxide, mercury, particulates or any other type of air pollution [1].

The major problem associated with extracting energy from the wind is due to the physical properties of air. The density of air is small and therefore, equipment designed to extract appreciable amounts of energy from moving air must be capable of intercepting large air areas. Also, the noise generated by wind turbines is considered and the interference with television reception, due to both rotating components and the fixed installation, may affect wind exploiting. Hazard due to failure of the moving components of the wind turbine is considered as another problem [1].

Akpinar [2] presented a work on statistical analysis of wind energy potential on the basis of the Weibull and Raleigh distribution for Agin-Elazig, Turkey. The work studied 5years measured wind speed data based on the Weibull and Rayleigh models. The Weibull distribution provides better power density estimation in all the twelve months than the Rayleigh distribution.

Shata [3], worked on evaluation of wind energy potential and electricity generation on the coast of Mediterranean sea in Egypt. Wind data for 10 coastal meteorological stations

along the Mediterranean Sea in Egypt was used in the analysis. Results shows that wind energy potential along the coast of Mediterranean sea in north Egypt is quite promising.

Celik [6], presented a work on statistical analysis of wind power density based on the Weibull and Rayleigh models at the southern region of Turkey. In his study one year monthly measured wind speed data was used, in the analysis Weibull model returns smaller error values in calculating the power density when compared to the Rayleigh model.

Ojosu [8] presented a statistical analysis of wind energy potential for power generation in Nigeria, 15 years (1968–1983) monthly average wind speed data was used for six sites at four distinctive regions in Nigeria using Weibull distribution. The analysis shows that wind turbine can generate up to 97MWh/year.

In Nigeria, wind energy is still at an infant stage because is almost an untapped renewable energy source. The

participation of government, private and individual to harness the utilization of this clean and inexhaustible energy source is very important for national development. Presently, the existing power plants in Nigeria are; Sayya Gidan–Gada, Sokoto with a capacity of 5kW/h, Dan–Jawa, Sokoto with a capacity of 0.75kW/h and Energy research, Benin with a capacity of 1kW/h, based on these capacity, the contribution its quite negligible to the total energy consumption in Nigeria [9].

In this study, wind energy potential for twelve locations in the northern and southern regions of Nigeria were analyzed using wind speed data at 10m height collected from Nigerian meteorological station NIMET Abuja for the period of (1990–2006). These locations are characterized by different geographical and climatological conditions.

This study provides useful information for developing wind sites and planning economical wind turbines capacity for the electricity production in Nigeria.

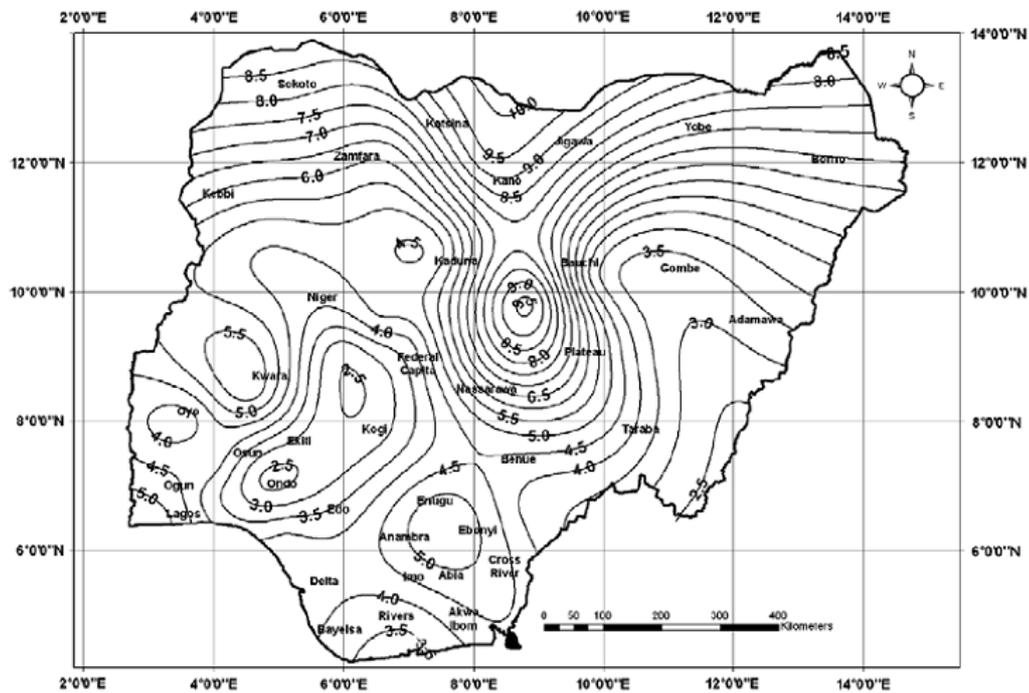


Figure 1: Predicted monthly average wind speeds (m/s) distribution at 10 m height in Nigeria (Source: Fadare, 2010).

Table 1: Geographical data for the selected locations

LOCATIONS	STATE	LAT (N)	LONG (E)	ALT(M)	ALT (FT)
KANO	KANO	11°59'47	8°31'0	476	1564
SOKOTO	SOKOTO	13°3'5	5°13'45	272	895
BAUCHI	BAUCHI	10°18'57	9°50'39	615	2020
MAIDUGURI	BORNO	11°50'47	13°9'37	299	984
ABUJA	ABUJA	9°15'0	6°55'60	246	810
JOS	PLATEAU	9°55'0	8°54'	1217	3996
ABEOKUTA	OGUN	7°9'0	3°21'0	66	219
LAGOS	LAGOS	6°27'11	3°23'45	34	114
ENUGU	ENUGU	6°26'25	7°29'39	247	813
OWERRI	IMO	5°28'60	7°1'60	158	521
CALABAR	CROSSRIVER	4°34'27	6°58'33	380	1249
PORTHARCOURT	RIVERS	4°47'34	6°59'50	465	1528

2. Wind Speed Data and Sites Descriptions

The present study is based on a data source measured at 10m height above ground level for twelve different locations in the northern and southern regions of Nigeria.

The wind speed data were collected during the period (1990 – 2006) at 10m height using a cup anemometer at the meteorological station. Fig. 1 shows the locations and distribution of the sites and table 1 shows the geographical features of these locations. These locations were selected for the analysis based on different geographical features.

3. Wind Speed Frequency Distribution

The knowledge of wind speed frequency distribution is very important factor to evaluate the wind potential in an area. If the wind speed in the location is known, then the power potential to the site can easily be obtained. Wind data obtained with various observation methods has a wide range therefore in wind energy analysis, it is necessary to have few parameters that can explain the behaviour 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, the common two are the Weibull and Rayleigh models [4].

The Weibull distribution function which is a two parameter distribution can be expressed as;

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

where f_w = Weibull probability density function
 k = shape factor
 c = scale factor

(1)

The corresponding cumulative probability function of the Weibull distribution is;

$$F_w(v) = 1 - \exp\left(-\left(\frac{v}{c}\right)^k\right)$$

F_w = Weibull cumulative distribution function

(2)

The Rayleigh distribution function is a special case of the Weibull distribution in which the shape factor is 2.0. Probability density and cumulative function of Rayleigh distribution are calculated as;

$$f_R(v) = \frac{\pi v}{2 v_m^2} \exp\left[-\left(\frac{\pi}{4}\right) \left(\frac{v}{v_m}\right)^2\right]$$
(3)

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

where $f_R(v)$ = Rayleigh probability density function

$F_R(v)$ = Rayleigh cumulative distribution function

3.1. Wind Power Density

The power density evaluation is a fundamental importance in the assessment of wind energy in a given area. The wind power density depends on the air density, the cube of the wind speed and the wind speed distribution. Therefore, this parameter is generally considered a better indicator of wind resource than the wind speed. It can be estimated by using the equation;

$$P(V) = \frac{1}{3} \rho A V^3$$
(5)

Where P = Power in watts (W)

A = Area perpendicular to wind speed vector in (m²)

V = Wind speed in (m/s)

ρ = Average density of air in (kg/m³)

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

Where P_W = Weibull Power

c = scale factor (m/s)

k = shape factor (dimensionless)

Γ = Gammafunction

$$P_R = \frac{3}{\pi} \rho v_m^3$$
(7)

Where P_R = Rayleigh Power

v_m^3 = mean speed

The yearly average error in calculating power densities using both Weibull and Rayleigh functions is obtained by using equation below;

$$\text{Error (\%)} = \frac{1}{12} \sum_{i=1}^{12} \left(\frac{P_{W,R} - P_{m,R}}{P_{m,R}} \right)$$
(8)

4. Results and Discussion

From the results obtained, table 2 presents yearly average monthly variation of Weibull parameters and wind speed for the northern and southern regions of Nigeria. The Weibull shape factor (k) for northern region of Nigeria varies between 4.13 – 7.47, the scale factor (c) varies between 2.58 – 10.76 m/s and wind speed varies between 2.36 – 10.12m/s, while for the southern region of Nigeria Weibull shape (k) varies between 3.51 – 10.07, the scale factor (c) varies between 3.35 – 5.91 and the wind speed varies from 3.02 – 5.47m/s.

It can be seen from table 3 that the favourable locations for wind power generation in northern region of Nigeria are; Maiduguri, Sokoto, Kano and Jos with values for Weibull

and Rayleigh varying between 162.51 – 924.45W/m² and 202.67 – 1256.11W/m² respectively, while for southern region of Nigeria the favourable locations are; Enugu and Lagos with values varying between 152.35 – 197.02W/m² and 172.21 – 188.73W/m².

Table 4, presents the percentage error for Weibull and Rayleigh models, from the results shown, it can be seen that Rayleigh models returns high percentage error in all the locations considered in this research.

Comparison of probability density function according to observed data with Weibull and Rayleigh models for the investigated sites is illustrated in the figures 2 - 5 below. It is seen from figure 2 and 3 that Bauchi shows peak value of probability density function as 1.01795 and 0.2937 for Weibull and Rayleigh, while figure 4 shows that Calabar has a peak value for Weibull probability density function as 0.8347 and Rivers has the peak value for Rayleigh probability density function as 0.2341 .

Table 2: Weibull distribution parameters at 10m height.

Locations	<i>k</i>	<i>c</i> (m/s)	<i>v</i> (m/s)
Northern region			
Kano	6.71	9.35	8.74
Sokoto	6.02	7.69	7.14
Bauchi	4.71	2.58	2.36
Maiduguri	5.47	5.90	5.45
Abuja	4.13	4.12	3.74
Jos	7.47	10.76	10.12
Southern region			
Abeokuta	3.51	3.35	3.02
Lagos	3.79	5.91	5.33
Enugu	8.92	5.80	5.47
Owerri	5.62	3.55	3.27
Calabar	10.07	4.60	4.42
Rivers	5.03	3.54	3.25

Table 3: Weibull and Rayleigh Power density

Locations	P _w (W/m ²)	P _R (W/m ²)	P _{mR} (W/m ²)
Northern region			
Kano	618.45	818.10	538.89
Sokoto	360.22	460.62	274.12
Bauchi	14.43	17.29	11.02
Maiduguri	162.51	202.67	120.49
Abuja	55.53	62.44	41.39
Jos	924.45	1256.11	713.95
Southern region			
Abeokuta	30.89	33.10	22.98
Lagos	172.21	188.73	119.74
Enugu	152.35	197.02	106.03
Owerri	34.74	41.78	26.92
Calabar	68.97	102.56	56.36
Rivers	35.08	41.85	26.59

Table 4: Weibull and Rayleigh % Error

Locations	% Error (Weibull)	% Error (Rayleigh)
Northern region		
Kano	23.33	61.29
Sokoto	30.95	65.18
Bauchi	28.04	50.74
Maiduguri	36.23	68.11
Abuja	33.48	49.84
Jos	29.28	42.87
Southern region		
Abeokuta	31.25	42.87
Lagos	40.99	58.13
Enugu	42.64	81.31
Owerri	30.77	61.46
Calabar	22.74	82.81
Rivers	32.67	58.38

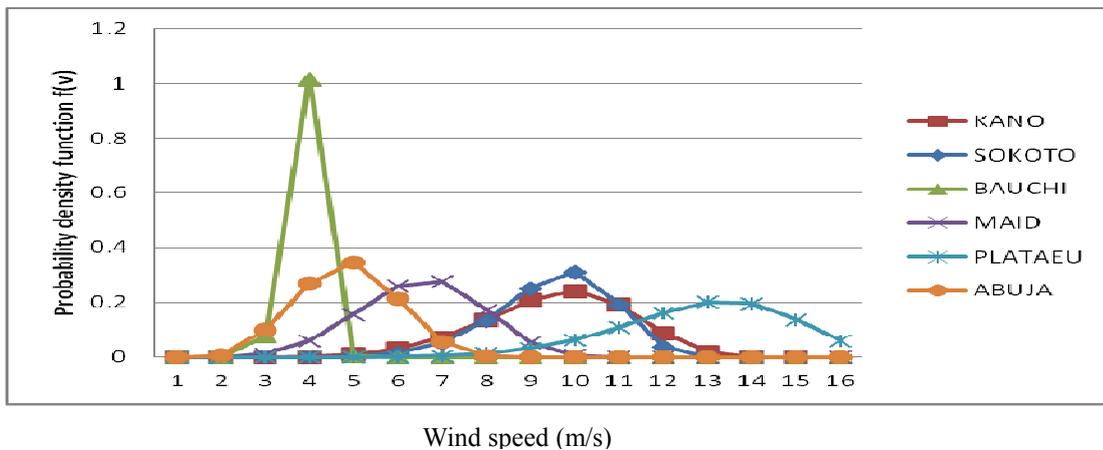


Fig 2: Comparison of Weibull probability density functions for northern region.

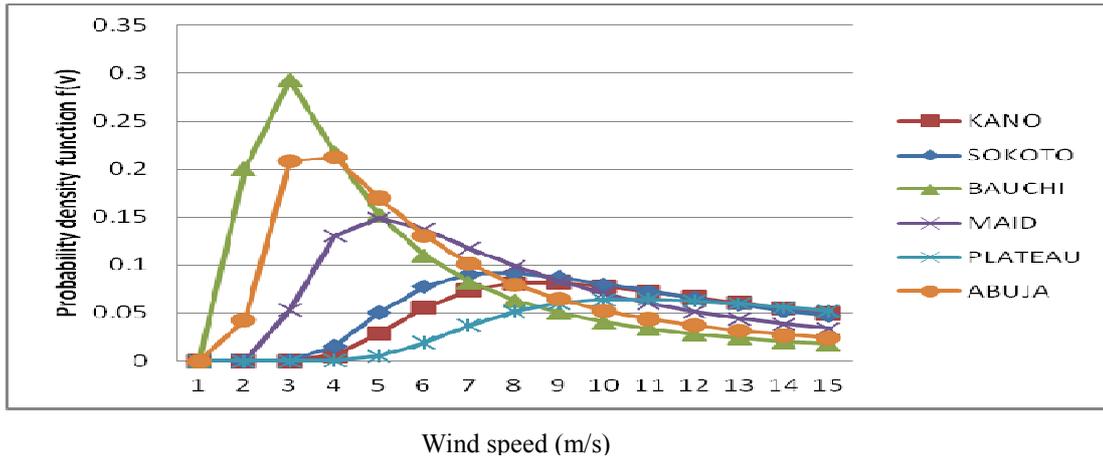


Fig 3: Comparison of Rayleigh probability density functions for northern region.

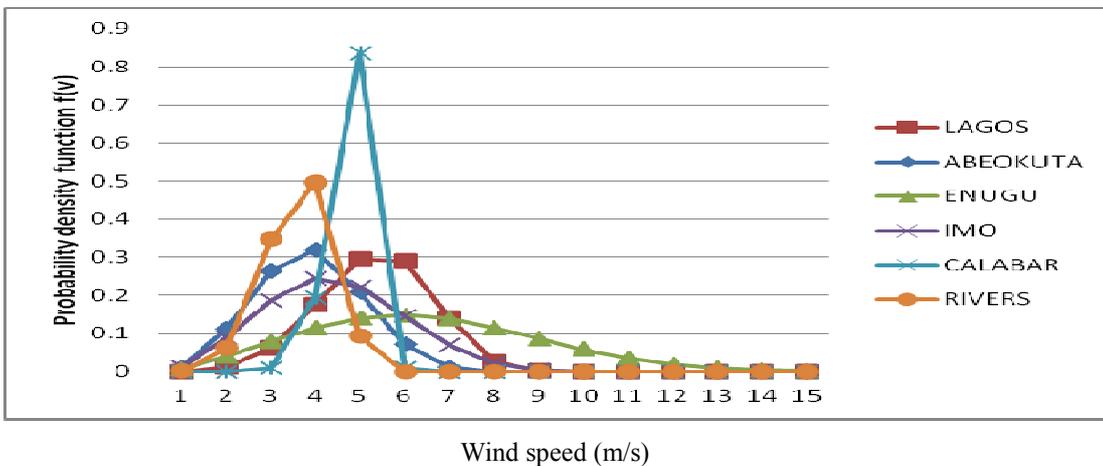


Fig 4: Comparison of Weibull probability density functions for southern region.

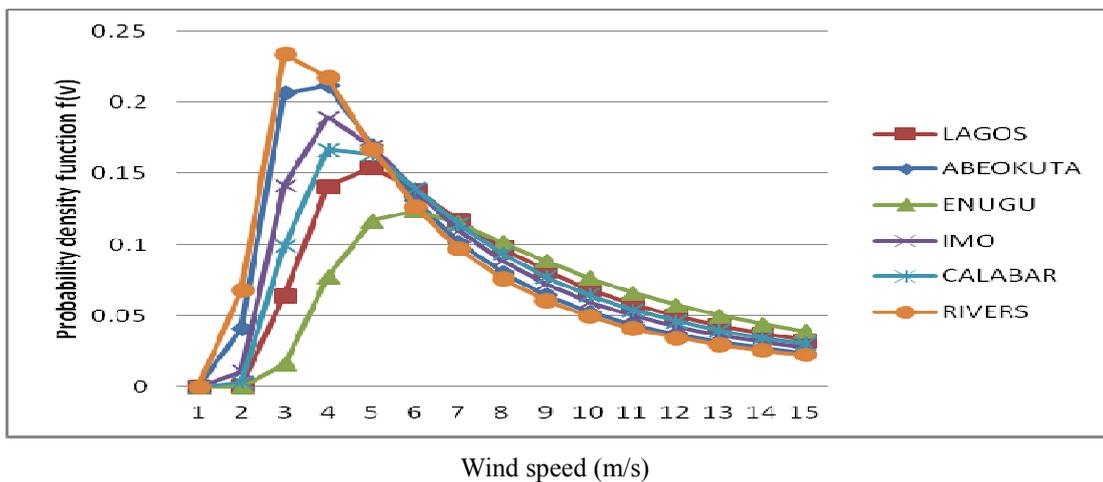


Fig 5: Comparison of Rayleigh probability density functions for southern region.

5. Conclusion

In this study, the monthly and yearly wind speed distribution and wind power density during the period (1990–2006) in the northern and southern region of Nigeria were evaluated. The wind speed frequency distribution of

the locations was found by using Weibull and Rayleigh distribution functions. It can be concluded as follows;

- (1). In the northern region, the highest average monthly wind speed occurred in Jos and was determined as 11.74m/s in February while the lowest wind speed occurred in Bauchi with value of 1.47m/s in December. The yearly

average annual wind speeds for these locations are shown in table 2.

(2). In the southern region, the highest average monthly wind speed occurred in Enugu and was determined as 6.47m/s in April while the lowest wind speed occurred in Rivers with value of 2.5m/s in November. The yearly average annual wind speeds for these locations are shown in table 2.

(3). The yearly average values for Weibull parameters (k and c) in the northern region varies between 4.71 – 7.47 and 2.58 – 10.76m/s respectively while for the southern region it varies between 3.51 – 10.07 and 3.35 – 5.91m/s respectively.

(4). In the northern region, the highest average monthly wind power occurred in Jos and was determined as 1469.81W/m² for Weibull and 1892.64W/m² for Rayleigh in February while the lowest average monthly wind power occurred in Bauchi and was determined as 3.87W/m² for Weibull and 3.72W/m² for Rayleigh in December. The yearly average annual wind powers for these locations are presented in table 3.

(5). In the southern region, the highest average monthly average wind power occurred in Lagos and was determined as 301.46W/m² for Weibull and 312.48W/m² for Rayleigh in the month of August while the lowest average monthly wind power occurred in Rivers and was determined as 15.77W/m² for Weibull and 18.53W/m² for Rayleigh in November.

(6). In calculating error in power density in both regions, the Weibull model returns smaller errors in calculating the power density compared to the Rayleigh model.

Finally, the Weibull distribution provides better power density estimation in both regions than the Rayleigh model since it returns lower error in power estimation.

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