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Analysis of wind energy potential in north east Nigeria

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Abstract: This research reports wind energy potential evaluation of two locations in the north east Nigeria (Bauchi and Borno). The evaluation is based on Weibull and Rayleigh models using 17 years mean monthly wind speed data covering the period (1990-2006). The result shows that Rayleigh is best fit model that describes the wind speed data at 10 m height. Reference mean power density (based on the measured probability distribution) was compared with those obtained from the Weibull and Rayleigh models. In calculating the percentage error, results shows that Weibull provided better power density estimation in all 12 months than the Rayleigh model. From this research work, it was found that Borno has high wind power density 273.16 W/m^2 for Weibull and 365.77 W/m^2 for Rayleigh in the month of June as compared Bauchi with highest power density of 31.45 W/m^2 for Weibull and 37.06 W/m^2 for Rayleigh in the month of May.

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

1. Introduction

Wind energy is currently the most economic renewable energy apart from hydropower, its usage versatility and ability to use it as a decentralized energy form make its applications possible in rural areas where it is technically and economically feasible in the country. The major challenge to using wind as a source of electricity generation is that wind is intermittent and it does not always blow when electricity is needed. However, wind power is one of the most the promising and cost – effective renewable.

In the 1980's, California purchased large quantities of wind power invest on operating experience needed to bring the cost of wind power down to a power installed in California, and another 1000W installed in other parts to generate electricity for over 750,000 homes.

The number of wind farms in US has increased substantially in the wind farms installed. The US Department of Energy projects that by the power, enough to generate electricity for 1.7 million homes, due to the power will fall. Currently, wind power costs between 3 and 6 cents making it one of the cheapest resources available [1].

Nigeria is subject to the seasonal rain – bearing south – westerlies, which blow strongly from April to October and to the dry and dusty North- East trade wind which blow strongly from November to March every year. Most areas sometimes experience some periods of doldrums in between these periods. In Nigeria, wind energy reserves at 10 m height shows that some sites have wind regime for between 1.0 to 5.1 ms^{-1}.

Energy supply in Nigeria is a major problem for both large and small scale purposes. Highly centralized production and distribution units have not been equally distributed thus becomes inadequate in meeting the economic needs of both urban and rural populace in Nigeria. With respect to this problem, solar and wind energy are some of the alternative sources of energy that can be exploited to meet some of the populace needs. It is therefore necessary to evaluate the wind regimes in the country and assess the potential of wind, installing wind energy conversion system for the generation of electricity.

In this context, over the years researchers have carried out a number of studies in order to assess the wind energy potential in some parts of the world. Shata [1] worked on the potential of electricity generation on the coast of Red Sea in Egypt. Celik [5] studied the distributional parameters used in assessment of suitability of wind speed probability density function. Ozoptal, et al [8] studied the regional wind energy potential of Turkey.

In this presentation, 17 years (1990 - 2006) monthly mean wind speed data are obtained from Nigeria Meteorological Agency (NIMET) Abuja for some selected locations in the North east Nigeria (Bauchi and Borno), were statistically analyzed to evaluate wind power density based on the Weibull and Rayleigh models.

2. Data Collection and Wind Speed Characteristics

Table 1. *Geographical data of the locations*

Locations	State	Latitude (N)	Longitude (E)	Altitude
Bauchi	Bauchi	10°18'57	9°50'39	615
Maiduguri	Borno	11°50'47	13°9'37	299

Table 2. *Summary of average wind speed V_m (ms^{-1}) and standard deviation σ (ms^{-1}).*

	Bauchi		Borno	
Months	V_m(ms^{-1})	σ	V_m(ms^{-1})	σ
Jan	2.43	0.40	4.94	1.35
Feb	2.09	0.62	5.85	1.71
Mar	1.99	0.68	6.27	1.31
Apr	2.62	0.57	6.02	1.03
May	3.16	0.77	6.27	1.10
Jun	2.91	0.71	6.88	1.15
Jul	2.82	0.57	6.19	1.23
Aug	2.44	0.43	5.03	0.98
Sep	2.54	0.55	4.33	0.98
Oct	2.17	0.57	4.07	0.93
Nov	1.68	0.59	4.52	0.89
Dec	1.47	0.63	5.06	1.39

Table 3. *Summary of average scale factor c (ms^{-1}), shape factor k and gamma function*

	Bauchi			Borno		
Months	*c*(m/s)	*k*	Γ	*c*(m/s)	*k*	Γ
Jan	2.58	7.21	0.826	5.45	4.11	0.729
Feb	2.31	3.77	0.713	6.48	3.81	0.715
Mar	2.22	3.23	0.683	6.79	5.53	0.782
Apr	2.85	5.27	0.774	6.42	6.85	0.818
May	3.46	4.67	0.753	6.71	6.65	0.813
Jun	3.19	4.68	0.753	7.24	6.91	0.819
Jul	3.06	5.75	0.789	6.68	5.81	0.790
Aug	2.61	6.66	0.813	5.42	5.92	0.794
Sep	2.75	5.34	0.776	4.71	5.06	0.767
Oct	2.39	4.27	0.736	4.43	5.03	0.766
Nov	1.88	3.12	0.677	4.87	5.90	0.793
Dec	1.66	2.54	0.637	5.59	4.11	0.729

Table 4. *Maximum and minimum values of wind speed (ms^{-1})*

Locations	Max. Vel. (m/s)	Month	Min. Vel. (m/s)	Month
Bauchi	3.16	May	1.47	Dec
Borno	6.88	Jun	4.07	Oct

In this study, statistical analyses of wind speed and power density available in selected states of north central Nigeria are investigated. Seventeen years monthly mean speed (1990-2006) from Nigeria Meteorological Agency (NIMET) Abuja at the height of 10m was used. Table 1 shows the geographical locations of the two locations in the north east of Nigeria (Bauchi and Borno). From the above Table it can be seen that Bauchi is located at longitude 9°50'39 East and latitude 10°18'57 North with a land scale slope of 615 meters. Borno is located at longitude 13°9'37 East and latitude 11°50'47 North with a land scale slope of 299 meters.

The summary of average wind speed V_m (ms^{-1}) and standard deviation σ (ms^{-1}) for the monthly distributional parameters for all the sites are presented in Table 2 below.

The summary of average scale factor *c* (ms^{-1}), shape factor *k* and gamma function for the monthly distributional parameters of the locations considered are presented in Table 3 below while Table 4 presents the maximum and minimum values of wind speed (ms^{-1}) for the two locations and months of their occurrences.

The frequency probability distribution for Bauchi in the month of January is presented in Table 5; the same pattern of table was computed for the two locations.

Table 5. *Frequency probability distribution for January for Bauchi.*

Vj	Vmj	fj	f(vj)	fw(vj)	fR(vj)
0 - 0.9	0.45	0	0.000	5.45262E-05	2.12698E-09
1 - 1.9	1.45	2	0.118	0.076813476	0.199965388
2 -2.9	2.45	14	0.824	1.017947398	0.293669502
3 - 3.9	3.45	1	0.059	0.005020743	0.217221871
4 - 4.9	4.45	0	0.000	6.33475E-21	0.152524121
5 -5.9	5.45	0	0.000	1.23105E-93	0.10994378
6 -6.9	6.45	0	0.000	0.000	0.082081098
7 -7.9	7.45	0	0.000	0.000	0.063266859
8- 8.9	8.45	0	0.000	0.000	0.05010226
9 - 9.9	9.45	0	0.000	0.000	0.040584663
10 - 10.9	10.45	0	0.000	0.000	0.03350453
11 - 11.9	11.45	0	0.000	0.000	0.028106483
12 - 12.9	12.45	0	0.000	0.000	0.023902753
13 - 13.9	13.45	0	0.000	0.000	0.020568503
14 - 14.9	14.45	0	0.000	0.000	0.017881314

2.1. Monthly Average Wind Speed and Standard Deviation

The monthly average wind speed and the standard deviation can be obtained using equation 1 and 2 below.

$$V_m = N^{-1}\left[\sum_{i=1}^{N} Vi\right] \quad (1)$$

$$\sigma = \left[\frac{1}{N-1}\sum_{i=1}^{N}(Vi - Vm)^2\right]^{1/2} \quad (2)$$

2.2. Wind Speed Probability Distributions

The wind speed data in time series format is usually arranged in the frequency distribution format since it is more convenient for statistical analysis. Therefore, the available time series data were translated into frequency distribution format. This process is illustrated for an example for the month of January for Bauchi as presented in Table 5.

The wind speed is grouped into classes (bins) as given in the first column of Table 5.The mean wind speeds are calculated for each speed class intervals are in second column. The probability density distribution is presented in the third column. The probability density obtained from Weibull and Rayleigh parameters are presented in the fourth and fifth columns.

The wind speed distributions and the functions representing them mathematically are the main tools used in the wind related literature. Their use include a wide range of applications, from the techniques used to identify the parameters of the distribution function to the use of such functions for analyzing the wind speed data and wind energy economics. Two of the commonly used functions for fitting a measured wind probability distribution in a given location over a certain period of time are the Weibull and Rayleigh. The probability density function of the Weibull distribution is given by;

$$f_w(v) = (k/c)\,(v/c)^{k-1}\exp\left[-(v/c)^k\right] \tag{3}$$

The corresponding cumulative probability function of the Weibull distribution is,

$$F_w(v) = 1 - \exp\left[-(v/c)^k\right] \tag{4}$$

$$V_m = c\,\Gamma\left(1+\frac{1}{k}\right) \tag{5}$$

$$c = \left[\frac{k^{2.6674}}{0.184+\left(0.816k^{2.73859}\right)}\right] \tag{6}$$

$$k = \left(\frac{\sigma}{v}\right)^{-1.090} \tag{7}$$

The Rayleigh model is a special and simplified case of the Weibull model. It is obtained when the shape factor k of the Weibull model is assumed to be = 2. The probability density and the cumulative functions of the Rayleigh model are given by,

$$f_R(V) = \frac{\pi}{2}\frac{v}{v^2_m}\exp\left[-\frac{\pi}{4}\left(\frac{v}{v_m}\right)^2\right] \tag{8}$$

$$F_R(V) = 1-\exp\left[-\frac{\pi}{4}\left(\frac{v}{v_m}\right)^2\right] \tag{9}$$

One of the most distinct advantages of the Rayleigh distribution is that the probability density and the cumulative distribution functions could be obtained from the mean value of the wind speed. The Rayleigh model has also widely been used to fit the measured probability density distribution.

2.3. Power Density Distribution & Mean Power Density

The power of the wind per unit area is given by;

$$P(V) = \frac{1}{2}PV^3 \tag{10}$$

Where ρ is assume to be 1.225 kg/m^3 in this paper.

The wind power density for the measured probability density distribution which serves as the reference mean power density as shown below;

$$P_{m.R} = \sum_{j=1}^{n}\left(\frac{1}{2}PV^3{}_{mj}f(vj)\right) \tag{11}$$

$$P_m(V) = \frac{1}{2}\rho.(V^3)_m \tag{12}$$

$$P_w = \frac{1}{2}\rho.c^3\Gamma\left[1+\frac{3}{k}\right] \tag{13}$$

$$P_R = \frac{3}{\pi}\rho.V_m{}^3 \tag{14}$$

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

$$\text{Error}(\%) = \frac{1}{12}\sum_{i=1}^{12}\left(\frac{P_{W,R}-P_{m,R}}{P_{m,R}}\right) \tag{15}$$

3. Analysis of Wind Speed Data

The surface wind characteristics and stochastic analysis of the wind speed data in the two locations of the north east part of Nigeria were carried out. It is seen from Table 2 that the highest average wind speed occurred in June (6.88 ms^{-1}) in Borno while the lowest average wind speed occurred in December (1.47 ms^{-1}) in Bauchi. The average scale factor c (ms^{-1}) ranges from 1.66 ms^{-1} in Bauchi to 7.24 ms^{-1} in Borno, while the shape factor k ranges from 2.54 in Bauchi to 6.91 in Borno as presented in Table 3.

3.1. Best – Fit Probability Distribution Model

The average monthly values of the correlation coefficient for the two locations in north east Nigeria ranges between 0.130 and 0.539 for the Weibull and the Rayleigh model ranges from 0.387 to 0.811 as indicated in Table 6.

The month – to – month comparison shows that Rayleigh model returns higher coefficient values in all the twelve months for Bauchi and Borno. It can be seen from Table 7 that in Borno, Rayleigh model returns higher coefficient in all months while Bauchi also returns higher coefficient values for Rayleigh except in the month of November and December.

Table 6. *Correlation coefficient values for all the location.*

	Bauchi		Borno	
MONTHS	W	R	W	R
JAN	0.130	0.430	0.356	0.519
FEB	0.336	0.439	0.539	0.716
MAR	0.407	0.437	0.425	0.762
APR	0.219	0.416	0.309	0.736
MAY	0.219	0.387	0.360	0.762
JUN	0.228	0.394	0.386	0.811
JUL	0.202	0.400	0.393	0.754
AUG	0.140	0.430	0.247	0.604
SEP	0.205	0.422	0.227	0.497
OCT	0.278	0.440	0.213	0.459
NOV	0.424	0.418	0.204	0.526
DEC	0.541	0.405	0.374	0.609
AVE				

Table 7. *Summary of best – fit probability distribution models.*

Months	Bauchi	Borno
Jan	Rayleigh	Rayleigh
Feb	Rayleigh	Rayleigh
Mar	Rayleigh	Rayleigh
Apr	Rayleigh	Rayleigh
May	Rayleigh	Rayleigh
Jun	Rayleigh	Rayleigh
Jul	Rayleigh	Rayleigh
Aug	Rayleigh	Rayleigh
Sep	Rayleigh	Rayleigh
Oct	Rayleigh	Rayleigh
Nov	Weibull	Rayleigh
Dec	Weibull	Rayleigh

4. Results and Discussion

The mean power density shows a large month – to – month variation as shown in Figure 1 and 2. From Figure 1 the maximum power density occurs in month of May for Rayleigh (37.06 W/m^2) while for Weibull is (31.45 W/m^2). From Figure 2 the maximum power density occurs in the month of June for Rayleigh (365.77 W/m^2) while for Weibull is (273.16 W/m^2).

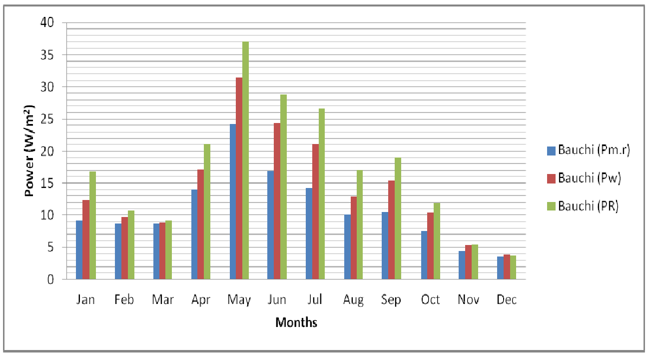

Fig 1. *Power density (W/m^2) for Bauchi ($P_{m.r,}$ P_w & P_R)*

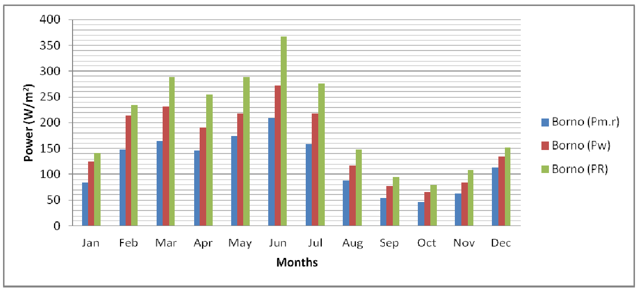

Fig 2. *Power density (W/m^2) for Borno ($P_{m.r,}$ P_w & P_R)*

From Figure 3, it can be seen that Rayleigh returns a higher percentage error in almost all the month expect for the month of December where Weibull have a lower percentage error than Rayleigh model. It can be seen that from Figure 4, Rayleigh returns a higher percentage error in all the twelve months.

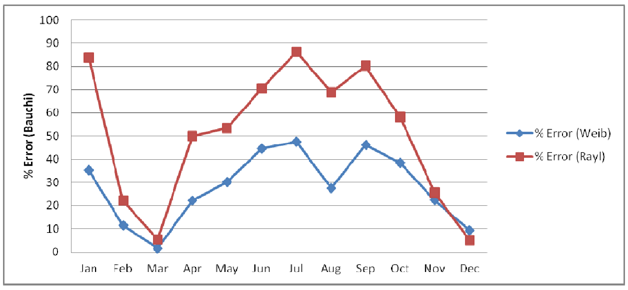

Fig 3. *% Error for Weibull and Rayleigh Bauchi*

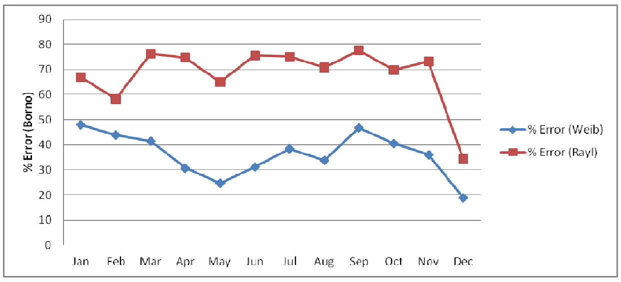

Fig 4. *% Error for Weibull and Rayleigh Borno*

5. Conclusion

In this study, it was found that Rayleigh returns a higher power density than Weibull and the highest power density is (365.77 W/m^2) for Rayleigh in Borno in the month of June, it was also found that Rayleigh returns the best fit probability distribution than Weibull in almost all the months in the two locations of north east part of Nigeria considered in this research work.

Finally, in calculating error in power density the Weibull model returns smaller error in calculating the power density compared to Rayleigh model in all locations. The power density is estimated by the Weibull model with a smallest error value of 1.5% for Bauchi in the month of March. From this research work, it was found that Borno in north east part of Nigeria has high wind power density for the generation wind energy with a maximum value of power density of 365.77 W/m^2 for Weibull. Borno can be classified under wind class II since the power density is greater than 100 W/m^2 while Bauchi can be classified under wind class I since the power density is less than 100 W/m^2.

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