Estimation of wind energy potential for two locations in North-West region of Nigeria

A. Ahmed
abdula2k2@yahoo.com
Department of Mechanical Engineering, Kano University of Science and Technology, Wudil, Nigeria.

***Abstract**: This paper presents an estimation of wind power potential of North West, Nigeria (Kano and Sokoto) on the basis of monthly wind speed data at 10m height from the ground. The data for the locations were collected from Nigeria metrological station, Abuja for the period of (2013-2017). Mean monthly values were used in calculation of Weibull distribution parameters c(scale factor ms^{-1}) and k (shape factor). The probability distribution function F (V) of wind speed, together with the duration function T (V) was evaluated for the period under investigation. From the statistical analysis of distributions, the Weibull distribution was found to have better fitting in the probability distribution functions F(V) and T(V). The value of energy and power density was found to be 1080.65W/m^2, 980.29W/m^2 and 1054.08W/m^2 for both Kano and Sokoto respectively.*
Keywords: Weibull distribution, Weibull parameters, Duration function, Wind energy.

I.INTRODUCTION

Wind energy is part of renewable energy source and is diffuse. The wind energy technology is mature and well established although it is still undergoing more technical development. Interest in wind energy is growing worldwide because of its environmental benefits and the advancement of its technology which is nearing being competitive with conventional energy technologies. Wind energy can be harnessed for grid and non-grid electricity generation, water pumping, irrigation and milling [1].

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 application 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 does not always blow when electricity is needed [3].

The wind systems that exist over the earth's surface are as result of variation in the pressure. These are due to the variations in solar heating, warm air rises and cooler air rushes in to take its place. Wind is merely the movement of air from one place to another due to uneven heating of the earth's atmosphere which causes temperature difference between land and seas, or mountain and valleys [5].

Wind speed generally increase with height above the ground, this is due to roughness of ground features such as vegetation and house which results to slowing down the wind speed.

Wind energy has been used since earliest civilization to grind grain, pump water from deep wells and power sail boat. Wind mills in Europe pre-industrial were used for many applications. The utilization of wind energy has been increasing around the world at an accelerating pace [7]. However, the development of new wind projects continues to be hampered by lack of reliable and accurate wind resource data in many parts of the world. Such data are needed 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 speeds is important for the design of wind farms, power generators and agricultural applications; such as irrigation [2].

These sources of energy are inexhaustible, clean and free. They offer many environmental and economic benefits in contrast to conventional energy sources. Wind energy is considered as a cost effective energy and its technological advancements allow it to compete with conventional power generation technologies [3].

Today, wind analysis provides remarkable information to researchers and designers that are involved in renewable energy studies, a large number of studies have been published amongst which are: Akpinar [1] presented a work on statistical analysis of wind energy potential on the basis of the Weibull and Rayleigh distribution for Agin-Elazig, Turkey. The work studies 5 years measured wind speed data based on the Weibull and Rayleigh models. The Weibull distribution provides better power density estimation in all twelve months than the Rayleigh models. Emami [4] worked on the statistical evaluation of wind speed and power density in the Firouzkouh region in Iran. The work studies an hourly average wind data which was observed for one year (2003) at Firouzkouh meteorological station, from his result he found that the region is quite favourable for wind power generation.

1.1 Wind speed data and sites description

The present study was based on data source measured at a height of 10m above the ground level for Kano and Sokoto North West, Nigeria. The wind speed data was collected from Nigerian meteorological station NIMET, Abuja for the period of (2013 - 2017). The geographical locations of Kano and Sokoto North West, Nigeria are presented in Table 1below. The locations have vegetation zone classified as Sudan zone and blessed with abundant vast land for agricultural activities.

However, the main objective of this present study is to estimate the wind energy potential for North-West region of Nigeria (Kano and Sokoto) because the demand of power is increasing due to increase in human activities. It has been forecast that the present source of energy which if fossil fuel will gradually be depicted, hence the use wind energy for this locations have been found quite promising as an alternative energy source.

TABLE 1: Geographical data for the selected location.

Locations	State	Lat (N)	Long (E)	Alt (m)	Alt (ft)
Kano	Kano	11°5947	8°310	476	1564
Sokoto	Sokoto	13°35	5°1345	272	895

Source: http://www.fallingrain.com

II.AVAILABLE POWER AND EXTRACTABLE POWER OF THE WIND

The power in wind is equal to energy per unit time. The energy available is the kinetic energy of the wind which is equal to the volume of air passing through an area (*A*) with wind speed in time (*t*).The power and energy density equation can be expressed as shown below [6];

Powerdensity;

$$P = \frac{1}{2}\rho A V_f^3 \qquad 1$$

$$\frac{P}{A} = \frac{1}{2}\rho V_f^3 \qquad 2$$

The actual power that can be extracted from wind depend on several factors, such as type of machine and rotor used, sophistication of blade design, friction losses, and losses in the machine or other equipment connected to the wind machine .

The possible extract maximum theoretical efficiency of a wind machine is 59.3% of the wind power, this is known as Betz limit.

The maximum power a wind machine can extract can be expressed in the equation below [12];

$$Maximum\ Power = \frac{0.593}{2} * \rho * V^3 * A \qquad 3$$

In practice, a wind machine extracts substantially less power than this maximum. For example, the wind mill itself may capture only 70% of maximum power. Bearing will lose another few percentage to friction, generators, gears and other rotating machinery [8].

where; *P* is power density *(Watts)*, *A* is area *(*m^2*)*, ρ is density and *V* is velocity *(m/s)*.

III.WIND SPEED DISTRIBUTION

In order to evaluate the wind energy potential of any site, it is important to derive the expected probability distribution of the site's wind speed. Weibull distribution parameter has been widely used in analysis of wind speed because it gives good match with the experimental data [11].

The wind speed probability distribution is essential in wind energy studies. The probability distribution could be used to evaluate the following [7];The capacity factor for a particular wind turbine generator used in producing any form of energy

i) The probability for the wind speed to lie in a certain interval especially when the speed is above is cut in speed of the turbine.

ii) The mean wind power density.

The probability density function for the wind velocity *v(m/s)* is given by [9];

$$f_w(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^k\right] \qquad 4$$

$$F_w(v) = 1 - \exp\left(\frac{v}{c}\right)^k \qquad 5$$

$$T(v) = 8760 \exp\left[-\left(\frac{v}{c}\right)^k\right] \qquad 6$$

The Weibull parameters (scale and shape factors) can be calculated analytically from the available wind speed data using the relations below [10];

$$c = \left[\frac{k^{2.6674}}{0.184 + \left(0.816^{k\,2.73859}\right)}\right] \qquad 7$$

$$k = \left[\frac{\sigma}{v}\right]^{-1.090} \qquad 8$$

where; f_W is Weibull probability density function, F_W is the Weibull cumulative distribution function, *T(V)* is frequency distribution duration function, *c* is the scale factor (m/s) and *k* is the shape factor (dimensionless).

IV. RESULTS AND DISCUSSION

In this study, the wind speed data were recorded for two locations in North West (Kano and Sokoto) for the period of (2013-2017) which have been statistically analyzed. The wind speed data of the two sites were obtained from Nigeria metrological station, Abuja. Based on these data, the wind speeds were analyzed and processed using spreadsheet and Wind Information System (WIS) software. The main results obtained are summarized as follows:

4.1. Wind characteristics and Weibull Parameters

The average yearly wind speed values V_m and Weibull parameters *k* and *c* are presented in Table 2 and Table 8 for both locations for the period of (2013 – 2017). It can be seen from Table 2 that, the average wind speed values are between 7.55 - 8.55ms^{-1} for Kano while for Table 8, the values ranges from 5.75 – 8.65ms^{-1} for Sokoto.

Similarly, values of the two Weibull parameters, the scale factor (ms^{-1}) and shape factor (dimensionless), calculated from the long term wind data for the sites studied and the values were found to be higher for Kano as compared to Sokoto with values of (shape factor) as 6.562 and 4.996 and values of (scale factor) as 8.516 ms^{-1} and 7.672ms^{-1} respectively.

TABLE 2: Values Obtained for Mean Yearly Wind Speed, Shape and Scale Factors

Year	2013	2014	2015	2016	2017
Average wind speed (V_m)	8.55	7.55	7.76	7..67	8.18
Shape factor (k)	5.56	7.08	4.49	8.35	7.33
Scale factor (c)	9.26	8.04	8.51	8.08	8.69

It can be seen below from Kano Tables of wind speed data, that the values of power and energy density increases with increase in the monthly average wind speed, while the duration function *T(V)* decreases with increase in wind speed. It is evident from the wind speed data, that the maximum average value of wind speed V_m in Kano occurs in year 2013 in the month of June with value of 12m/s and having highest power and energy density of 105.08W/m^2 and 758.84kWh/m^2 respectively, while the lowest power and energy density occurred in year 2015 with values 101.49W/m^2 and 755.08kWh/m^2. From the Weibull probability distribution function, it is noticeable that the highest probability density function *F(V)* occurred in year 2016 in the month of May with value of 0.3792 and the lowest occurred in year 2015 in month of May with value of 0.0187. For the duration function *T(V)*, the highest value occurs in year 2013, in the month of November with value of 8238.55 while the lowest value occur in year 2013 month of June with value of 127.12.

TABLE 3: Kano power and energy density wind speed for year 2013

Months	Wind speed (m/s)	Power density (W/m^2)	Energy density (kWh/m^2)	F(V)	T(V)
Jan	10.4	686.17	510.51	0.1510	1295.10
Feb	8.7	401.69	269.93	0.2228	4309.97
Mar	8.3	348.79	259.50	0.2117	5073.92
Apr	9.3	490.66	253.27	0.2197	3135.80
May	8.9	430.03	319.94	0.2246	3917.62
Jun	12.0	1054.08	758.94	0.0284	127.12
Jul	10.0	610	453.84	0.1836	1882.92
Aug	8.0	312.32	232.37	0.198	5613.14
Sep	7.6	267.78	192.80	0.175	6268.04
Oct	6.1	138.46	103.01	0.0814	7936.74
Nov	5.6	107.13	77.13	0.0573	8238.55
Dec	7.7	278.49	207.19	0.1812	6111.99

TABLE 4: Kano power and energy density wind speed for year 2014

Months	Wind speed (m/s)	Power density (W/m^2)	Energy density (kWh/m^2)	F(V)	T(V)
Jan	6.9	200.39	149.09	0.2476	6245.29
Feb	6.6	175.37	117.85	0.2070	6842.82
Mar	8.0	312.32	232.37	0.3254	3339.25
Apr	9.1	459.68	330.97	0.1693	793.55
May	8.4	361.55	268.99	0.2941	2242.84
Jun	9.6	539.69	388.58	0.0776	262.63
Jul	9.1	459.68	342.00	0.1693	793.55
Aug	7.6	267.78	199.22	0.3195	4479.35
Sep	6.4	159.91	115.13	0.1802	7181.87
Oct	5.8	119.02	88.549	0.1094	7934.85
Nov	6.4	159.91	115.13	0.1802	7181.87
Dec	6.7	183.47	136.50	0.2206	6655.53

TABLE 5: Kano power and energy density wind speed for year 2015

Months	Wind speed (m/s)	Power density (W/m^2)	Energy density (kWh/m^2)	F(V)	T(V)
Jan	6.4	159.91	118.97	0.1478	6633.61
Feb	8.5	374.62	260.73	0.1944	3239.64
Mar	8.9	430.03	319.94	0.1817	2578.54
Apr	7.3	237.30	170.86	0.187	5301.99
May	11.9	1027.95	764.80	0.0187	96.41
Jun	10.7	747.28	538.04	0.0716	534.10
Jul	7.8	289.48	215.37	0.198	4455.07
Aug	7.2	227.68	169.40	0.1837	5464.37
Sep	6.9	200.39	144.28	0.1719	5932.07
Oct	5.5	101.49	755.08	0.0999	7609.83
Nov	6.4	159.91	115.13	0.1478	6633.61
Dec	5.6	107.13	79.70	0.1051	7520.06

TABLE 6: Kano power and energy density wind speed for year 2016

Months	Wind speed (m/s)	Power density (W/m^2)	Energy density (kWh/m^2)	F(V)	T(V)
Jan	9.0	444.63	330.85	0.1949	747.767
Feb	7.5	257.34	179.11	0.3494	5121.04
Mar	6.9	200.39	149.00	0.2478	6703.12
Apr	7.1	218.33	157.20	0.2845	6237.12
May	8.1	324.18	241.19	0.3792	3156.10
Jun	9.9	591.88	426.16	0.0197	37.47
Jul	8.7	401.67	298.86	0.2787	1371.76
Aug	7.7	278.49	207.19	0.3716	4487.98
Sep	7.2	227.68	163.93	0.3023	5980.09
Oct	6.0	131.76	980.29	0.1067	8060.01
Nov	6.9	200.39	144.28	0.2478	6703.48
Dec	7.0	209.23	155.67	0.2662	6478.34

TABLE 7: Kano power and energy density wind speed for year 2017

Months	Wind speed (m/s)	Power density (W/m^2)	Energy density (kWh/m^2)	F(V)	T(V)
Jan	7.2	227.68	169.4	0.1992	6811.10
Feb	7.2	227.68	158.47	0.1992	6811.10
Mar	7.1	218.33	162.43	0.1869	6980.20
Apr	8.6	387.10	279.36	0.3127	3471.06
May	10.2	647.34	481.62	0.0916	345.17
Jun	10.1	628.48	452.51	0.1078	432.41
Jul	9.7	556.73	414.21	0.1805	935.20
Aug	9.1	459.68	342.00	0.2781	2158.21
Sep	7.5	257.34	185.29	0.2363	6238.65
Oct	6.7	183.47	136.50	0.1400	7551.36
Nov	6.8	191.80	138.10	0.1512	7423.82
Dec	8.0	312.32	232.37	0.2895	5080.46

TABLE 8: Values Obtained for Mean Yearly Wind Speed, Shape and Scale Factors

Year	2013	2014	2015	2016	2017
Average wind speed (V_m)	6.94	6.95	6.95	8.56	5.75
Shape factor (k)	5.58	5.59	6.34	3.70	3.77
Scale factor (c)	7.51	7.52	7.46	9.50	6.37

TABLE 9: Sokoto power and energy density wind speed for year 2013

Months	Wind speed (m/s)	Power density (W/m^2)	Energy density (kWh/m^2)	F(V)	T(V)
Jan	7.8	289.48	215.37	0.2571	2546.15
Feb	7.8	289.48	194.53	0.2571	2546.15
Mar	7.6	267.78	199.22	0.2697	3008.41
Apr	8.1	324.18	233.41	0.2287	1905.44
May	8.8	415.70	309.28	0.1363	776.34
Jun	8.4	361.55	260.32	0.1917	1351.52
Jul	7.4	247.19	183.91	0.2767	3487.86
Aug	6.0	131.76	980.29	0.1997	6584.28
Sep	5.3	90.82	65.39	0.1305	7594.15
Oct	4.4	51.96	386.00	0.0610	8328.43
Nov	5.2	85.77	61.76	0.1213	7704.38
Dec	6.5	167.52	124.64	0.2454	5605.71

TABLE 10: Sokoto power and energy density wind speed for year 2014

Months	Wind speed (m/s)	Power density (W/m^2)	Energy density (kWh/m^2)	F(V)	T(V)
Jan	8.0	312.32	232.366	0.2403	2131.78
Feb	6.8	191.80	128.892	0.2649	4955.35
Mar	8.1	324.18	241.189	0.2298	1925.78
Apr	7.4	247.19	177.974	0.2768	3512.03
May	9.2	474.10	353.399	0.0856	399.85
Jun	8.6	387.99	279.359	0.1656	1054.29
Jul	7.6	267.78	199.225	0.2701	3032.11
Aug	6.1	138.46	103.013	0.2085	6422.36
Sep	4.7	63.33	45.599	0.0791	8149.23
Oct	6.0	131.76	98.029	0.1987	6600.74
Nov	5.1	80.92	58.26	0.1116	7815.45
Dec	5.8	119.02	88.50	0.1786	6931.25

TABLE 11: Sokoto power and energy density wind speed for year 2015

Months	Wind speed (m/s)	Power density (W/m^2)	Energy density (kWh/m^2)	F(V)	T(V)
Jan	7.4	247.19	183.91	0.3148	3387.55
Feb	8.3	348.79	234.39	0.2102	1225.39
Mar	7.9	300.75	223.76	0.2740	2079.42
Apr	7.7	278.49	200.51	0.2964	2580.21
May	8.7	401.69	298.86	0.1364	618.37
Jun	8.1	324.18	233.41	0.2446	1624.30
Jul	6.3	152.53	113.48	0.2447	6219.57
Aug	6.0	131.76	98.03	0.2066	6812.95
Sep	4.9	71.77	51.67	0.084	8170.95
Oct	5.7	112.97	84.05	0.1684	7305.37
Nov	5.3	90.81	65.39	0.1221	7812.40
Dec	7.1	218.33	162.43	0.3142	4218.04

TABLE 12: Sokoto power and energy density wind speed for year 2016

Months	Wind speed (m/s)	Power density (W/m^2)	Energy density (kWh/m^2)	F(V)	T(V)
Jan	8.5	374.62	278.72	0.1488	4516.38
Feb	7.0	209.23	140.60	0.1236	6342.87
Mar	7.3	237.30	176.55	0.1312	6007.86
Apr	12.1	1080.65	778.07	0.0647	756.90
May	10.1	628.48	467.59	0.1312	2498.55
Jun	9.9	591.88	426.16	0.1359	2732.57
Jul	8.5	374.62	278.72	0.1488	4516.38
Aug	4.4	51.96	38.66	0.0451	8267.37
Sep	4.4	51.96	37.41	0.0451	8267.37
Oct	8.1	324.18	241.19	0.1455	5032.82
Nov	12.4	1163.04	837.39	0.0548	599.95
Dec	10	610.00	453.84	0.1336	2614.52

TABLE 13: Sokoto power and energy density wind speed for year 2017

Months	Wind speed (m/s)	Power density (W/m^2)	Energy density (kWh/m^2)	F(V)	T(V)
Jan	4.7	48.50	36.08	0.1585	6980.29
Feb	7.6	267.78	179.95	0.1382	1259.26
Mar	6.0	131.76	98.03	0.2254	3950.53
Apr	3.8	33.47	24.01	0.1225	7595.98
May	9.1	459.68	342.00	0.0346	191.63
Jun	7.8	289.48	208.42	0.1216	1031.68
Jul	6.1	138.46	103.01	0.2242	3753.55
Aug	4.7	63.33	47.12	0.1852	6377.17
Sep	3.5	26.15	18.83	0.1014	7889.97
Oct	5.2	85.77	63.81	0.2114	5504.82
Nov	5.3	90.81	65.39	0.2153	5317.87
Dec	5.6	107.13	79.70	0.2235	4740.14

It can be seen below from Sokoto Tables of wind speed data, that the values of power and energy density increases with increase in the monthly average wind speed, while the duration function *T(V)* decreases with increase in wind speed. It is evident from the wind speed data, that the maximum average value of wind speed V_m in Sokoto occurs in year 2016 in the month of April with value of 12.1m/s and having highest power and energy density of 1080.65W/m^2 and 778.07kWh/m^2 respectively, while the lowest power and energy density occurred in year 2017 month of September with values 26.15W/m^2 and 18.83kWh/m^2. From the Weibull probability distribution function, it is noticeable that the highest probability density function *F(V)* occurred in year 2015 in the month of January with value of 0.3148 and the lowest occurred in year 2016 in months of August and September with values of 0.0451 respectively. For the duration function *T(V)*, the highest value occurs in year 2013, in the month of October with value of 8328.43 while the lowest value occur in year 2017 month of May with value of 191.63.

V.CONCLUSION

In this study, wind speed data for Kano and Sokoto North West, Nigeria have been statistically analyzed. The Weibull probability distribution function have been derived from the wind speed data obtained from Nigeria metrological station, Abuja for the period of (2013-2017) and the probability function *F(V)* and duration function *T(V)* were evaluated.

It is quite evident that the wind energy in Kano and Sokoto North West, Nigeria can provide up a maximum value of 980.29kWh/m^2 annually, respectively, which is significant in generating electricity and water pumping. The power density obtained from the wind in Kano and Sokoto North West, Nigeria can provide up a maximum value of 1054.08W/m^2 and 1080.65W/m^2 respectively, which is quite promising for wind energy generation.

It can be concluded that the Weibull distribution is suitable to represent the actual probability of wind speed data for the

North West region of Nigeria.

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