Estimation of the Wind Energy Potential of Kebbi State Based on Weibull Distribution Function

SHAMSUDEEN, Umar (1) ; SAIDU, Sunbo Akanji (2) ; ABDULHAKIM, Akinlabi Abiola (3) ; ADENLE, Johnson G. (4)
Department of Electrical Engineering, Kebbi State Polytechnic Dakingari, Kebbi State, Nigeria.

Abstract:- The performance of a proposed energy source depends on the breeze distribution pattern for a region. This study was embarked upon to estimate the wind energy potential in Kebbi State based on Weibull distribution function. Estimation of the potential the proposed energy source in the region provides a means of establishing the viability of deploying energy source in generating electricity in that region. The Data on Breeze speed in Kebbi State spanning a period of five years (2017-2021) was obtained from Nigeria Metrological Agency (NIMET). The mean speeds were obtained at a height of 10.1m and transformed to a height of 50m using power law coefficient value of 0.143 to allow for accurate evaluation of energy source to compensate for height of modern wind turbines. The study revealed that monthly mean breeze speed values for Kebbi State was mostly between 3 to 4minutes per second. The maximum monthly rate is 6.372 minutes per second was recorded in February. From the results obtained, the shape parameter range between 1.404 and 1.844 an indication that the wind distribution is skewed towards lower velocities. The average power density value for the years studied was found to be 64.88(W/m^2). This result classifies Kebbi State using the European Wind Energy Association (EWEA) as poor. However, the wind energy distribution in the study area could be used to power light loads. Selection of α value of 0.4, a factor which depends on the terrain improved the monthly wind speed to a range of 2.531 m/s to 9.733 m/s. The mean yearly velocity also range from 4.486 m/s to 7.731 m/s. These values is greater than the yearly mean speed range of 2.863 m/s to 4.933 m/s recorded when α is 0.143 This increment in wind speed will greatly impact on the breeze power density of the region. The study therefore recommended that further work should be done to determine the actual value of power law coefficient (α) in Kebbi State to enable us take a more decisive decision on the energy potential of Kebbi State. However, to deploy wind energy on a large scale in Kebbi State effort has to be geared towards designing wind turbine with low rated speed to match the frequency probability distribution in Kebbi State.

Keywords:- Wind Energy, Weibull Distribution, Wind Power Density, Wind Mean Speed, Power Law Coefficient.

I. INTRODUCTION

Researches have proven that fossil fuels are limited resources and the current rates of exploitation it expected to deplete within the next centuries, this is a well established fact. The use of fossil fuels for the production of energy releases carbon-dioxide in the lower layer of the atmosphere resulting to bad weather conditions including climate change, floods, intensive rainfalls and droughts respectively. To curb the menace, it is the responsibility of each country to device alternative energy resources to reduce the ever rising price of fossil fuels (coal and oil) with renewable energy alternatives such as wind, solar and other energy sources [1]. Although the conventional sources of energy using fossil fuel burning have been able to produce surplus amount of energy, its finite nature is a concern for the future. Employing environment friendly and non-toxic sources for energy production has gained wide acceptance across the globe. This is because these sources which include wind, solar and hydro are non-depletable and so containing sustained potentials for abundant energy generation. This has led to various efforts at measuring and assessing their potentials for electricity generation. Wind Energy Technology (WET) application involves three important stages: Resource assessment, hardware development and installation, and also electricity generation and distribution [2]. The first stage, which in this case is the potential resource assessment and the objective of this research work is very important to the other two stages and therefore to WET.

Wind energy an alternative, inexhaustible, clean power source. The wind industry started as a niche business aimed at increasing environmental awareness, but in the past years, it has established itself as the most competitive kind of renewable energy [3].

Unlike other non-conventional energy sources (e.g., tidal, solar), the wind has a more variable and diffuse energy flux [4]. Breeze speed distribution has an important influence on the performance of a wind turbine [5]. For this reason, wind has been deeply studied in several world regions to investigate the possibility of deploying it as a means of generating electrical energy in such regions.[6] investigated the status and wind power potential of the city of Shahrbabak in Kerman province in Iran. The study statistically analyzed the potential of wind power generation using three-hour interval mean wind speed data spanning a period from 1997 to 2005. The numerical values of the dimensionless Weibull shape parameter (k) and Weibull scale parameter (c) were determined. Annual values of “k” ranged from 1.725 to

1.930 with a mean value of 1.504, while annual values of "c" were in the range of 4.848–6.095 with a mean value of 5.314 (m/s). With the average wind power density of 100W/m2, it is found that the city is not an appropriate place for construction of large-scale wind power plants, but is suitable for employment of off-grid electrical and mechanical wind driven systems. An economic evaluation was done in order to show feasibility of installing small wind turbines. It was concluded that it costs 18 cents for 1 kWh which is 5 cents more than the market price. Each turbine of 10kW can supply power for icebox, washer, water pump, TV, lighting, electrical fan, charger, and air conditioning units for small houses. In order to utilize wind energy in the region, it is recommended to install small size wind turbines for electricity supply for both public buildings and private houses.

[7] Assessed wind energy potential as a power generation source in five locations in south western part of Nigeria. In this study, the wind speed characteristics and energy potential in the five selected locations were investigated using monthly mean wind speed data of 51 years measured continuously using three cup generator anemometer at a height of 10 m above sea level obtained from the Nigeria Meteorological Agency (NIMET). The data were subjected to the 2-parameter-Weibull and other statistical analyses. The outcome showed that the wind speed measured at a height of 10 m ranged from 1.3 to 13.2 m/s while the modal wind speed ranges from 3.0 to 5.9 m/s." 83.6% of the data were found to be greater than 3.0 m/s. The average monthly wind speed ranged from 2.72 to 7.72 m/s. Seasonally, average wind speeds ranged between 3.47 to 6.55 m/s and 3.83 to 6.94 m/s for dry (October to March) and wet (April to September) seasons, respectively. The two parameters of the Weibull statistics were found to lie between $2.99 \leq k \leq 5.32$ and $3.02 \leq c \leq 8.57$, respectively. The annual mean power densities are 65.09, 145.07, 176.96, 387.07 and 87.34 W/m2 for Abeokuta, Akure, Ibadan, Ikeja and Oshogbo respectively. It was further shown that the respective mean annual values of the most probable wind speed are 3.82, 4.97, 5.23, 7.03 and 4.01 m/s, while the annual values of the wind speed carrying maximum energy are 4.12, 5.48, 5.87, 7.50 and 4.55 m/s. These results indicate that wind speed has the viable potential for wind-to-electricity at height of 10 m for most of the locations assessed but it will be more viable in all the stations at a height above 10 m.

[8] Carried out an assessment of the wind energy potential of five sites in South-West (SW) of Buenos Aires province in Argentina. Two and five minutes high-resolution wind data spanning a period of 2009 to 2012 were used in this research work. Wind speed at 30, 40 and 60m heights from the anemometer position was computed using the power law. Turbulence intensity and wind direction were also analyzed. Statistical analyses were conducted using two-parameter Weibull distribution. A set of commercial wind turbines were techno-economically analyzed in the selected sites. The result from this work indicates that SW of Buenos Aires province represents a promising area for wind energy extraction, thus encouraging the construction of wind farms for electricity generation.

[8] Investigated the potential for wind energy development in Lagos, a fast growing city in southwestern Nigeria. A preliminary evaluation of Lagos's wind energy resource was undertaken to determine the suitability of the city for wind energy development. This study shows that wind energy is available in Lagos and it could be used to generate electricity. The mean annual wind speed was above 5m/s. The study also indicates that the annual energy and capacity factor for the site were 512.11MWh and 9.7%, respectively based on specification of wind turbine known as Vestas V42-600. The study was concluded with recommendation of extending the work to study wind energy at different locations in the country so as to ascertain their suitability for the establishment of wind turbine farms.

[9] Estimated the Weibull parameters for wind energy analysis across the UK. The study used wind speed data for the period 1981 to 2018, collected at 38 surface observation stations, the study presents a comprehensive assessment of wind speed characteristics by means of statistical analysis using the Weibull distribution function. The estimated Weibull parameters are used to evaluate wind power density at both station and regional levels and important, turbine-specific wind energy assessment parameters. It is shown that the Weibull distribution function provides satisfactory modeling of the probability distribution of daily mean wind speeds, with the correlation coefficient generally exceeding 0.9. Site-to-site variability in wind power density and other essential parameters is apparent. The Weibull scale parameter lies in the range between 4.96 m/s and 12.06 m/s, and the shape parameter ranges from 1.63 to 2.97. The estimated wind power density ranges from 125W/m2 to 1407W/m2. Statistically significant long-term trends in annual mean wind speed are identified for only 15 of the 38 stations and three of the 11 geographical regions.

This research work intends to carry out an estimation of wind potential of Kebbi State based on Weibull Distribution Function using available metrological data from Nigeria Metrological Agency (NIMET) in Kebbi State.

The result of this research effort will indicate whether or not it is feasible to generate electricity using wind potential in the state. Conclusion on the wind potential capability of the studied region (Kebbi) will be drawn based on European Wind Energy Association (EWEA) wind classification system.

II. STATEMENT OF THE PROBLEM

The price of fossil fuel is on the increase and continuous usage of fossil fuel in the generation of electricity constitutes greenhouse effects. This led countries to focus on other energy consumption and exploit renewable energy sources. Wind is a renewable, inexhaustible, and clean energy source. It is therefore a good substitute to the conventional method of generating electricity using the depletable fossil fuel. Electricity is generated from wind energy using turbines. The operation of turbines in an area to generate electricity largely depends on the potential of the available wind resources.

ISSN No:-2456-2165

In other word, a wind project may be an effort in futility if pre- assessment of the wind energy potential of an area is not done before the installation of wind turbines. This is because wind speed and its distribution have an important influence on the performance of a wind turbine [4]. This research work is therefore concerned with the estimation of the wind potential of Kebbi State based on Weibull Distribution Function using available metrological data. The study will reveal whether or not it is economically feasible to generate electricity using wind energy in Kebbi State.

III. OBJECTIVES OF THE STUDY

The main aim of this research work is to estimate the wind energy potential of Kebbi State from the wind distribution pattern in Kebbi State based on Weibull Distribution Function using available metrological data. This research work shall meet the following specified objectives:

- To quantify the monthly and annual variation of wind mean speed, standard deviation and wind power density in Kebbi State over the period of study.
- To show the variation of wind frequency probability density (Weibull) with wind speed for Kebbi State.
- To classify the wind potential of Kebbi State from the processed data using Pacific Northwest National Laboratory (PNNL) and European Wind Energy Association (EWEA) wind classification system.

IV. METHODOLOGY

A. *Description of Location*

The study was conducted in Kebbi State (11.4942ºN, 4.2333ºE) located within north-western Nigeria. Kebbi State is bordered by Sokoto State, Niger State, Zamfara State, Dosso Region in the Republic of Niger and the nation of Benin. It has a total area of 36,800 km^2 .Kebbi State consists of 21 Local Government Areas, four emirate councils (Gwandu, Argungu, Yauri and Zuru), and 35 districts. And it has a total population of 4,440,050 as at 2016 population census.

B. *Method of Data Collection*

Wind speed data for the region of Kebbi State spanning a period of five years (2017-2021) was obtained from Nigeria Metrological Agency (NIMET). The mean speeds were obtained in knots at a height of 10.1m. This mean speeds were converted into m/s and transformed to a height of 50m using power law to allow for accurate estimation of wind energy to compensate for the height of modern wind turbines. The most frequent adopted value of 0.143 (1/7) was used for the power co-efficient (α) [10].

Although, wind speed frequency distribution can be represented by different probability density functions such as Weibull, Rayleigh, three parameter beta, lognormal, and gamma distributions. Weibull distribution is one of the most commonly used methods for determining wind energy potential and this probability distribution function were used in this research.

C. *Procedure for Data Analysis*

In order to accurately evaluate the wind energy potential of Kebbi State and clarify its characteristics, the long-term meteorological observations from NIMET was used. Clearly, wind speed is a random variable, and probability density functions could be calculated from analyzing the variation of wind speed over a period of time. Wind speed frequency distribution has been represented by different probability density functions. Weibull distribution function was used in this research.

➢ *Weibull Probability Density Function*

The use of Weibull distribution requires that the shape factor (k) and the scale factor (c) be initially determined from the collected field data [11]. The Weibull probability density distribution function used to describe the wind speed distribution is given by (1) [12].

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

Where (k$> 0,\ v > 0, c > 1$)

The corresponding cumulative density function is (F (v))

$$F(v) = 1 - \exp[\,(-v/c)^{k}\,] \quad (2)$$

f(v) is the wind speed probability for speed v, c is the Weibull scale parameter, and k is the shape parameter. When the average speed and variance of the data is calculated, k and c can be obtained from the following equations [12].

$$k = 0.83v^{0.5} \quad (3)$$

$$c = \frac{v}{gamma(1+(\frac{1}{k}))} \text{ [13].} \quad (4)$$

The empirical method of Justus (EMJ) can also be used to find the value of k based on the mean and standard deviation of wind speed; V and σ_v [14]. This formula is given in (5).

$$k = \left(\frac{\sigma_v}{V}\right)^{-1.086} \quad (5)$$

Where ($1 \le k \le 10$)

Once the shape parameter, k, is estimated using (5), an alternative, empirical method proposed by Lysen can also be used to obtain the value of scale parameter c has shown in (6) [15].

$$c = v(0.568 + \frac{0.433}{k})^{-\frac{1}{k}} \quad (6)$$

➢ *Wind Power Density*

Wind power that flows at speed v through a blade sweep area A, increases with the cube of the wind speed and the areas, it is given by

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

ρ is the density of air at sea level with a mean temperature of 15 °C and a pressure of 1 atm (1.225 kg/m^3) and v is the mean wind speed (m/s). Then the corrected monthly air density in (kg/m3) is calculated as follows [13][16].

$$\rho = \frac{\bar{p}}{R_d \bar{T}} \quad (8)$$

where $\bar{T}$ is average monthly air temperature in Kelvin (K); $\bar{p}$ is the average of monthly air pressure in Pascal (Pa), and Rd is gas constant for dry air which its value is 287 J/kg K. It is important to mention that most of the available units of pressure are provided in H-Pascal (1H-Pascal = 100 Pa). However, in this study the value of ρ is assumed to be (1.225 kg/m^3).

In order to evaluate available wind resource at a site, it is required to calculate the wind power density. It shows how much energy is available at the site for conversion to electricity by a wind. The wind power density (W/m^2) can be estimated from the Weibull parameters as indicated in (9) [17].

$$P(v) = \frac{1}{2}\rho c^3 \text{ gamma } (1 + \frac{3}{k}) \quad (9)$$

- *Most Probable and Maximum Energy Carrying Wind Speed*

The evaluation of the most probable and maximum energy carrying wind speeds is very important to wind energy assessors. They can be evaluated from (10) and (11) [13].

$$v_{mp} = c(\frac{k-1}{k})^{\frac{1}{k}} \quad (10)$$

$$v_{Emax} = c(\frac{k+2}{k})^{\frac{1}{k}} \quad (11)$$

Where: v_{mp}= most probable wind speed and v_{Emax} = maximum energy carrying wind speed. The wind turbine operates most efficiently if $v_r \cong v_{Emax}$, where v_r is the rated speed of the turbine.

- *Most Probable and Maximum Energy Carrying Wind Speed*

A variety of wind speed profile models have been established to describe the height dependence of wind speed [17]. Among which the simple power-law model is more often used as a handy tool to conduct vertical wind speed extrapolation in the wind energy community [18].

$$V = V_R \times (\frac{z}{z_R})^{\propto} \quad (12)$$

Where v is the daily wind speed estimated at the prospective height of a wind turbine, z (is the rotor's height above the ground level), V_R is the reference wind speed measured at the reference height Z_R (10.1m in our case), and α is the power law coefficient whose value is taken as 0.143 in this research work. It is to be noted that the power law coefficient does not remain constant for all locations and may vary as a function of numerous factors, such as the nature of terrain, wind speed, and atmospheric stratification conditions [17, 19].

TABLE 1
VARIATION OF MONTHLY WIND SPEED AND STANDARD DEVIATION FOR KEBBI STATE AT 50M HEIGHT

MONTH	PARAMETER	2017	2018	2019	2020	2021
JAN	V	3.918	4.710	1.626	6.211	5.606
	δ	0.745	0.558	0.437	1.278	1.099
FEB	V	4.061	5.169	1.731	6.372	4.315
	δ	0.46	0.497	0.558	0.706	0.433
MAR	V	3.606	4.773	1.772	5.398	3.877
	δ	0.548	0.777	0.408	0.827	0.553
APR	V	3.726	5.040	1.917	5.621	4.027
	δ	0.733	0.995	0.523	1.153	0.580
MAY	V	4.356	6.065	2.876	5.982	4.731
	δ	1.454	2.820	1.901	1.547	1.124
JUNE	V	3.640	5.126	1.788	5.793	4.049
	δ	1.229	1.357	1.028	1.596	1.099
JULY	V	3.397	3.772	3.439	3.960	3.626
	δ	1.435	1.336	1.380	0.894	1.331
AUG	V	3.731	3.981	3.918	4.418	3.647
	δ	0.702	0.819	0.600	0.748	0.679
SEP	V	3.230	3.058	3.489	3.532	3.274
	δ	0.914	1.187	0.670	0.651	1.072
OCT	V	2.626	2.043	2.584	2.418	2.522
	δ	1.014	0.884	0.973	0.727	0.715
NOV	V	4.329	1.615	3.812	4.910	3.790
	δ	0.816	0.472	1.104	1.040	0.925
DEC	V	5.023	1.938	5.398	4.585	4.231
	δ	0.722	0.441	0.952	0.904	0.574

V. RESULTS AND DISCUSSIONS

➢ *Monthly Variation of Mean Wind Speeds*

From Table 1 the monthly mean wind speed values are between 3 and 4 m/s most time. Only few values are below 2.5m/s and above 5m/s. The maximum monthly value of 6.372 m/s occur in February. Monthly variation of mean wind speed is also depicted graphically in Figure 1.

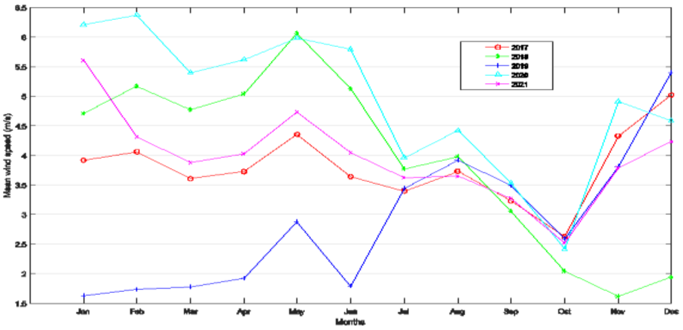

Fig 1: Graph Showing Monthly variation of wind speed for Kebbi State.

➢ *Yearly Weibull Wind Speed Parameter*

Table 2 shows the yearly weibull parameters for Kebbi State for the period under study. The table shows how the scale parameter, c in m/s varies with dimensionless k parameter referred to as shape parameter. It is evident from the table that high value of scale parameter indicate high value of the average measured velocity. A higher value of shape parameter between 2 and 3 indicate that the distribution is skewed towards high velocity while shape parameter between 1 and 2 indicate that the distribution is skewed towards lower wind velocity. In this study at a height of 50m, the shape parameter range between 1.404 and 1.844, an indication that the wind distribution is skewed towards lower velocities.

Table 2: Yearly Weibull parameters and Characteristics speed at 50m height in (m/s) for Kebbi State at α = 0.143

Year	K	c (m/s)	V_{mp} (m/s)	V_{op} (m/s)	V (measured)
2017	1.619	4.247	2.344	6.981	3.804
2018	1.648	4.407	2.500	7.138	3.941
2019	1.404	3.142	1.295	5.903	2.863
2020	1.844	5.553	3.634	8.273	4.933
2021	1.655	4.446	2.539	7.177	3.975

➢ *Monthly Variation of Power Density and Energy*

Power density was computed from the average wind velocity for the same months in the years under study. That implies that the average velocity for January was obtained by obtaining the average of the wind speeds for January from 2017 to 2021. The power density was computed using (9). The result is shown in Table 3. For Kebbi State, the maximum power density of 100. 684 (W/m^2) occur in the month of May while the lowest value of 24. 206 (W/m^2) occur in October. The energy value range from 17.428 kwh/m^2/month to kwh/m^2/month kwh/m^2/month, these values correspond to a range of 212.04 kwh/m^2/year to 881.99 04 kwh/m^2/year . The average power density value for the years studied was found to be 64.88(W/m^2).

[6] reported that according to a classification done by European Wind Energy Association (EWEA), the wind characteristics and categories are indicated below: Fairly good (6.5 m/s, ≈300–400W/m2); good (7.5 m/s, ≈500–600W/m2); very good (8.5 m/s, ≈700–800W/m2). This classification is at a height of 10m.In our current study, the average power densities for the years under consideration at 50m height is 64.88 W/m^2 (Table 2) and the average measured wind speed for the years under study is 3.903 m/s , thus Kebbi State is a poor location for the installation of wind turbine for the generation of electrical energy on a large scale based on EWEA. Figure 2 also shows the monthly variation of wind power density for Kebbi State. However, the location could be a good option for installation of small-scale wind turbine to supply electricity to power light loads such as electric bulb, fans, radio and charger.

Table 3: Monthly Wind Power Density and energy for whole year for Kebbi State at 50m height in (m/s)

Month	k	c (m/s)	Vmp	Vop(m/s)	P/A (W/M^2)	E/A (kwh/m^2/ month)	$\bar{V}$ measured
JAN	1.744	4.955	2.708	6.841	82.706	59.549	4.414
FEB	1.727	4.858	2.624	6.759	79.131	56.974	4.330
MAR	1.636	4.342	2.181	6.330	61.961	44.612	3.885
APR	1.674	4.552	2.361	6.504	68.593	49.387	4.066
MAY	1.819	5.402	3.096	7.220	100.684	72.493	4.802
JUNE	1.676	4.567	2.374	6.516	69.087	49.743	4.079
JULY	1.583	4.055	1.937	6.096	53.687	38.654	3.639
AUG	1.647	4.404	2.234	6.382	63.890	46.001	3.939
SEP	1.512	3.678	1.620	5.793	44.077	31.736	3.317
OCT	1.296	2.639	0.781	5.011	24.206	17.428	2.439
NOV	1.595	4.115	1.988	6.145	55.366	39.864	3.691
DEC	1.708	4.748	2.529	6.667	75.218	54.157	4.235

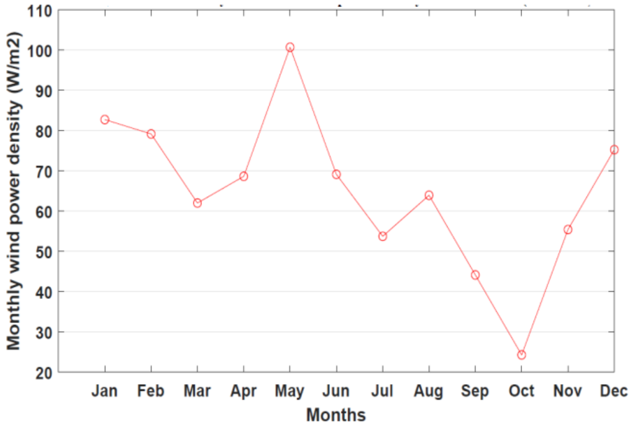

Fig 2 Graph Showing Monthly Variation of wind power density for Kebbi State (2017-2021)

➢ *Wind Speed Frequency Probability Density*

The average wind power density for the data spanning the period under study was computed from the daily wind speed. It was found to be 56.44 w/m$^{2.}$ The average values of K and C were calculated. The wind power density (64.88 w/m^2) for January to December for the years under study was also computed using Weibull distribution. The two wind power density were matched using data solver in Excel. The new values of k and c are 2.464525 and 4.359583 respectively. The result is the graph of frequency probability density for Kebbi State.

The result shows that 22.5% of the wind speed distribution is between 3 m/s and 4m/s., about 17% of the wind speed distribution is within 5 m/s. 10% of the wind speed is 6 m/s while about 4% is 7m/s. Less than 1. 6% of the wind distribution is above 8 m/s.

This thus imply that to generate electricity in the study area using wind turbine, turbines with rated wind speed of 3m/s will be most suitable. Figure 3 shows wind speed frequency probability density for Kebbi State.

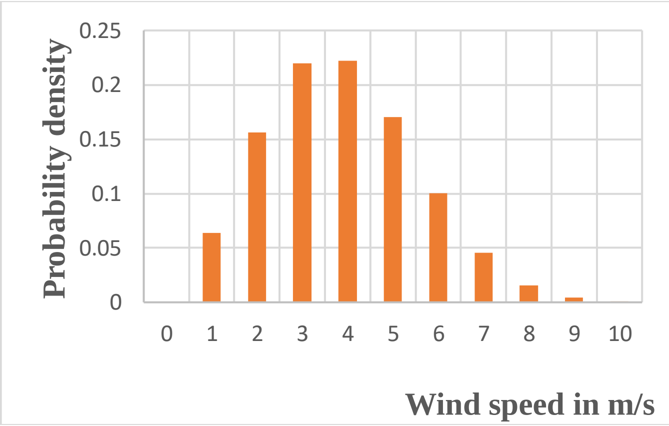

Fig 3 Graph Showing Monthly Variation of wind power density for Kebbi State (2017-2021)

Table 4: Monthly wind mean speed at 50m height in (m/s) for Kebbi State at α = 0.4

Month	Parameter	2017	2018	2019	2020	2021
JAN	V	6.140	7.381	2.547	9.733	8.786
FEB	V	6.364	8.099	2.712	9.985	6.762
MAR	V	5.650	7.479	2.776	8.459	6.075
APR	V	5.839	7.897	3.004	8.808	6.311
MAY	V	6.826	9.504	4.507	9.373	7.414
JUNE	V	5.704	8.032	2.801	9.078	6.345
JULY	V	5.324	5.911	5.389	6.205	5.683
AUG	V	5.846	6.228	6.140	6.924	5.716
SEP	V	5.062	4.792	5.467	5.535	5.130
OCT	V	4.115	3.201	4.050	3.789	3.952
NOV	V	6.784	2.531	5.974	7.695	5.940
DEC	V	7.871	3.037	8.459	7.185	6.630
AVERAGE		5.960	6.174	4.486	7.731	6.229

VI. SUMMARY OF FINDINGS

The study revealed that the monthly mean wind speed values for Kebbi State are 3 to 4 m/s in most cases and a maximum monthly value of 6.372 m/s as recorded in February. In this study the shape parameter range between 1.404 and 1.844 an indication that the wind distribution is skewed towards lower velocities. The average power density value for the years studied was found to be 64.88(W/m^2). This result classifies Kebbi State using the European Wind Energy Association (EWEA) as poor. However, breeze energy distribution in the study area could be used to power light loads such as electric bulb, fans and chargers. To deploy wind energy on a large scale in Kebbi State effort has to be geared towards designing wind turbine with low rated speed to match the frequency probability distribution in Kebbi State.

VII. RECOMMENDATIONS

It is recommended that further work shouuld be done to determine the actual value of power law coefficient (α) in Kebbi State to enable us take a decisive decision on the energy potential of Kebbi State. This is because a value of $\alpha = 0.143$ was used in this research work (commonly used value in wind energy research). This value majorly depends on the nature of the terrain in the study area. However, using a value of α = 0. 4, improve the monthly wind speed to a range of 2.531 m/s to 9.733 m/s. The mean yearly velocity also range from 4.486 m/s to 7.731 m/s. These values is greater than the yearly mean speed range of 2.863 m/s to 4.933 m/s recorded when $\alpha = 0.143$ This increment in wind speed will greatly impact on the wind power density of the region.

VIII. CONCLUSION

Wind energy is a substitute to fossil fuel. However, the performance of an installed wind turbine for the generation of electricity greatly depends on the wind speed and its distribution. Analysis of wind speed data of Kebbi State was carried out using Weibull distribution function. Result of the study revealed that the average power density is below the criteria for classifying the region as a good wind potential region for the installation of wind turbine for a large-scale generation of electricity base on EWEA. However, the wind potential of the region could be used to power light loads. If large scale wind energy harnessing is required, research efforts have to be channeled to design wind turbines that would operate at a rated speed matching the wind distribution for Kebbi State.

REFERENCES

[1]. Sahin, D. Progress and recent trends in wind energy progress in energy and combustion. *Science; 30:501* 43., 2004.

[2]. Ajayi, O.O., Fagbenle, R.O. & Katende, J. Assessment of Wind Power Potential and Wind Electricity Generation Using WECS of Two Sites in South West, Nigeria. *International Journal of Energy Science*, **1**, 78-92., 2011.

[3]. Molenaar, D. Cost-effective design and operation of variable speed wind turbines. Ph.D. thesis. The Netherlands: Delft University Press. 2003.

[4]. Weisser D. Wind energy analysis of Grenada: an estimation using the Weibull density function. *Renewable Energy*; 28:1803–12., 2003.

[5]. Ayodele, T., Jimoh, A., Munda J. &. Agee T. Wind distribution and capacity factor estimation for wind turbines in the coastal region of South Africa. *Energy Conversion and Management* 64:614–25., 2012.

[6]. Mostafaeipour A., Sedaghat, A. Dehghan-Niric A. & Kalantar V. Wind energy feasibility study for city of Shahrbabak in Iran. *Renewable and Sustainable Energy Reviews* (15) 2545–2556., 2011.

[7]. Nze-Esiaga, N. & Okogbue, E.C. Assessment of Wind Energy Potential as a Power Generation Source in Five Locations of South Western Nigeria. *Journal of Power and Energy Engineering*, **2**, 1-13., 2014.

[8]. Sibila A. Genchi, Alejandro J. Vitale, M. Cintia Piccolo & Gerardo M. E. Perillo .Wind energy potential assessment and techno-economic performance of wind turbines in coastal sites of Buenos Aires province, Argentina, *International Journal of Green Energy*, 13:4, 352-365., 2016.

[9]. Sanusi, Y. &. Abisoye, G. Estimation of Wind Energy Potential in Southwestern Nigeria. *The Pacific Journal of Science and Technology* 12(2):161-166., 2017.

[10]. Shu, R. & Jesson, M. (2021). Estimation of Weibull parameters for wind energy analysis across the UK.

[11]. Seguro J. & Lambert T. Modern estimation of the parameters of the Weibull wind speed distribution for wind energy analysis. Department of Mechanical engineering, Colorado State University, USA,. 1999.

[12]. Chang TJ, Wu YT, Hsu HY, Chu CR, Liao CM. Assessment of wind characteristics and wind turbine characteristics in Taiwan. *Renewable Energy*; 28: 851–71., 2003.

[13]. Keyhani, A., Ghasemi-Varnamkhasti M, Khanali, M, Abbaszadeh, R. Anassessment of wind energy potential as a power generation source in the capital of Iran, Tehran. *Journal of Renewable and Sustainable Energy; 35: 188–201., 2010.*

[14]. Justus G., Hargraves W., Mikhail A., & Graber D. Methods for estimating wind speed frequency distributions. *Journal of Applied Meteorology*. 17(3), 350–353, 1978.

[15]. Lysen H. Introduction to Wind Energy (CWD Publication,The Netherlands), No. CWD 82–1., 1983.
[16]. Aslan Z, Mentes S, Yukselen MA, Tolun S. Global wind energy assessment of Turkey and a case study in the northwest. In*: Int. Energy Symp*. 21st Century, Istanbul, 28–30., 1994.
[17]. Z. R. Shu, Q. S. Li, Y. C. He, and P. W. Chan, "Observations of offshore wind characteristics by Doppler-LiDAR for wind energy applications, *Appl. Energy*. 169, 150–163, 2016.
[18]. "R. N. Farrugia, "The wind shear exponent in a Mediterranean island climate, *Renewable Energy* 28(4), 647–653, 2003.
[19]. J. S. Touma, "Dependence of the wind profile power law on stability for various locations,*J. Air Pollut. Control Assoc*. 27(9), 863–866, 1977.