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WIND ENERGY POTENTIAL AT KANO AIRPORT VIA WEIBULL PARAMETERS

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ABSTRACT

A clean, source free and environmentally friendly alternate source of energy such as wind energy can be use for providing sustainable power supply to remedied an epileptic and unreliable power supply systems. This paper carried out an analysis of wind speed data at Mallam Aminu Kano International Airport in Nigeria using Weibull distribution methods to determine the wind features and its potentials necessary for power supply generation. Weibull parameter methods have been chosen for this analysis because of its efficiency. A six years (2009-2014) monthly mean wind speed data measured at 10 *m* height was collected and extrapolated to 100 *m* height level for statistical analysis. The average wind speed, standard deviation, Weibull scale and shape parameters has been analyzed for both 10 *m* and 100 *m* height levels. The minimum average wind speed was found to be 5*m/s* and the maximum average wind speed was 12.5 *m/s* at the 10 *m* height level, the Weibull scale parameters were found generally higher than the shape parameters. The Weibull parameter models were validated by RMSE. The site has been found to have great potentials for utility power generation capacity.

Keywords: Weibull parameters, power density, wind speed data, mallam aminu kano, Weibull distribution function, renewable energy sources.

1. INTRODUCTION

The ever increasing demand for energy and global climate change due to green house gas (GHG) emission from the usage of fossil fuel and its fast rate of depletion for power generation is becoming a source of concerns on air pollution and global warming [1].These prevailing conditions necessitated an urgent need for alternate energy sources [2]. RES, such as biomass, wind, geothermal, tide and solar power systems are clean, source free and environmental friendly alternative energy sources [3].

For decades, electric power supply situation in Nigeria has been a major source of serious concern. The epileptic power supply throughout the nation has hindered the socio-economic growth and, subsequently, increase air pollution due individual stand-alone diesel generators and hindered industrialization of the country. Various government incentives and policies has little or no effect to improve the availability and reliability of the electric power supply [4]. The aviation industries especially the Navigation and communication equipment require apart from availability, a reliable power sources because of their sensitivity to reliable and safe Aircraft navigation. The need for an alternate RES of power supply away from the National grid and diesel generator is inevitable.

Renewable energy sources (RES) technology such as wind turbine (WT) though stochastic in nature is a popular RES for electricity generation because it is source free and inexhaustible in nature. Wind energy is one of the most preferable renewable energy resources being utilize around the globe because of its sustainability and green nature as well as its integratable equipment for proper sizing and configuration [5]

Both in the past and presently many research works have been carry out to look into wind speed potentials in terms of power generation using such tools and models as artificial neural network, autoregressive integrated moving average, autoregressive moving average, Monte Carlo simulations, Weibull and Rayleigh distribution methods in various nations around the world [6-12].

In Nigeria, several studies have been carried out in various locations on the assessment of wind speed variability and its energy potentialities [4, 13, 14] using various analytical model tools such as Weibull and Rayleigh distribution parameter methods, artificial neural network, amongst other several analytical methods however none of these literatures has considered Kano Airport despite its economical viabilities.

The aim and objective of the current study is to carry out the analysis of wind energy potential using the Weibull distribution functions for Kano Airport, Nigeria to determine its suitability for a carbon free wind turbine autonomous power system supply.

2. MATERIALS AND METHODS

2.1 Site location and data collection

Kano Airport is located in the Northern part of Nigeria with coordinates $12^o02^I55^{II}$N $8^o31^I20^{II}$E and elevation at 476 meters above the sea level. Mallam Aminu Kano International Airport is the first Airport in Nigeria, being a colonial Royal Air Force station the first Aircraft landing was in 1925 before independence and began commercial services in 1936. Its strategic location serves as Air Traffic control hub and fuel stopover between Africa and Europe for flight operations

In this paper six years (2009 - 2014) monthly mean speeds wind data measured at a height of 10m for Mallam Aminu Kano International Airport were obtained from the Nigerian Metrological Agency (NIMET) Kano Airport. The average wind speed was extrapolated to standard height of 100m for wind characteristics analysis. The data were statistically analyzed based on Weibull model. Weibull parameters such as probability density function, shape factor k, scale factor c and the gamma function Γ and power densities were then evaluated.

2.2 Mean wind speed and standard deviation

Mean monthly wind speed V_m and standard deviation σ were obtained from the wind speed data using equations (1) and (2) respectively [15]

$$V_m = \frac{1}{N}\left(\sum_{i=1}^{N} V_i\right) \tag{1}$$

$$\sigma = \left[\frac{1}{N-1}\sum_{i=1}^{N}(V_i - V_m)^2\right]^{1/2} \tag{2}$$

Where, V_m is the mean wind speed in *m/s*; σ is the standard deviation of the observed data in *m/s*; V_i is the monthly wind speed in *m/s*; N is the number of measured monthly wind speed data.

2.3 Weibull parameters computation of the wind speed

In statistical methods, wind speed variation is described by the Weibull distribution function [16]. Two parameters (shape parameter k and scale parameter c) functions are popularly use for studies. The probability density function of the Weibull distribution is given by the expressions in equation (3) [17].

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

Where v is the average wind speed in *m/s*, c *(m/s)* is the scale parameter and k (dimensionless) is the shape parameter.

From the mean and variance of the wind speed the Weibull's probability distribution parameters can be determined using equations (1) and (2) [17] as follows:

$$k = \left(\frac{\sigma}{v}\right)^{-1.086}, \quad (1 \le k \le 10) \tag{4}$$

$$c = \frac{\mathrm{v}}{\Gamma\left(1+\frac{1}{\mathrm{k}}\right)}\frac{m}{s} \tag{5}$$

Where $\Gamma(x)$ is the gamma function of x and mathematically expressed thus as:

$$\Gamma(\mathrm{x}) = \int_0^\infty \mathrm{t}^{\mathrm{x}-1}\exp(-\mathrm{t})\mathrm{dt} \tag{6}$$

From equation (3) above the mean wind speed on the basis of Weibull parameters could be defined [18] as

$$v_a = c\Gamma\left(1+\frac{1}{k}\right)\frac{m}{s} \tag{7}$$

To evaluate the performance criteria of the Weibull distribution model for the wind speed estimation with respect to the meteorological data obtained, an analysis on the basis of root mean square error (RMSE) equation is shown in equation (8).

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(y_i - x_j\right)^2} \tag{8}$$

y_i is the i^{th} wind speed data and x_j is the j^{th} Weibull estimated value and N is the observed wind data number.

2.4 Wind speed vertical height extrapolation

Wind speed varies as a function of the height above ground up to an optimum altitude. It is therefore necessary to determine the wind speed at the height of the wind turbine's hub in terms of the measured wind speed. The equation for variations in wind speed with hub height is a power law expressed in equation (9) as follows: [5], [19].

$$v_2 = \left(\frac{h_2}{h_1}\right)^{\alpha} v_1\left(\frac{m}{s}\right) \tag{9}$$

Where $v_1$is the measured wind speed at a known height $h_1$while $v_2$is extrapolated wind speed at practical height h_2. The exponent, α, is the surface roughness coefficient or wind shear factor and dependent on height, time of the day, season of the year, nature of the terrain, wind speed and temperature and could be determined by equation (10). [20]

$$\alpha = \frac{[0.37 - 0.088 ln v_1]}{1 - 0.088 ln\left(\frac{h_1}{10}\right)} \tag{10}$$

2.5 Wind power density estimation

The wind power available at a given site is assessed by calculating the mean wind speed V_m passing through the rotor blade sweep area A of a wind turbine is a function of the cube of the velocity and is as shown in equation (11). [16].

$$P(v) = \frac{1}{2}\rho A V_m^3 W \tag{11}$$

Where ρ (kg/m^3) is the standard air density and is taken as $1.225 kg/m^3$ for this work, thus it is a function of altitude, air pressure and temperature. A (m^2) is the swept area. The wind power density (wind power per unit area) based on the Weibull probability density function (PDF) can be calculated by the formula given as equation (12). [19]

$$P(v) = \frac{P(v)}{A} = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) \tag{12}$$

3. RESULTS AND DISCUSSIONS

3.1 Average variation of wind speed

Average monthly wind speed measured at height of 10 *m* level for the six year period data are plotted below:

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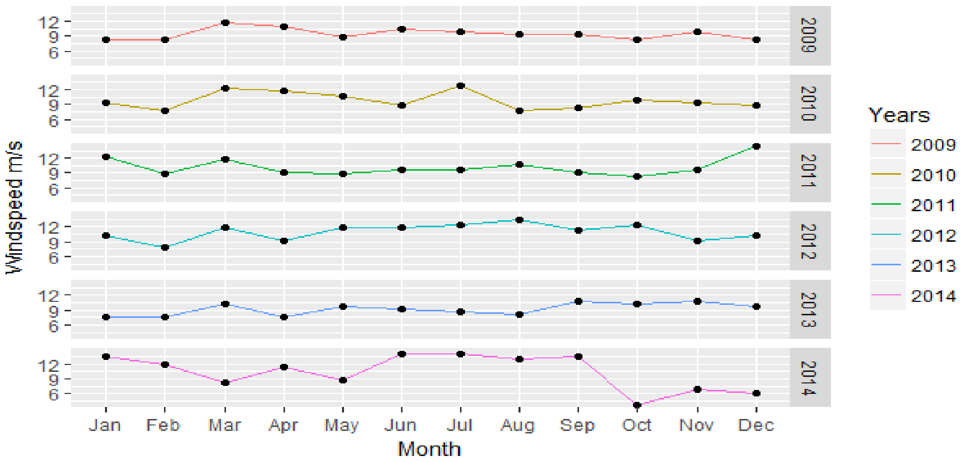

Figure-1. Monthly mean wind speed for the six year period at 10 *m* height.

It could be observe that the months of February and October had the lowest mean wind speed values while the Months of March and July had the peak mean wind speed values. These are due to the transitions between the Dry season - Harmattan season and hot season - Rainy season periods. In between these periods the mean wind speed is relatively moderate. The year 2011 had the highest mean wind speed while the year 2013 mean wind speed was moderate. The annual mean wind speed for the six years period plotted in Figure-2 further indicates the above analysis; the months of February and October were lowest with mean wind speed value of 8.66 m/s and 8.75 m/s respectively while the months of March and July were high with values of 11.07 *m/s* and 11.23 *m/s* respectively

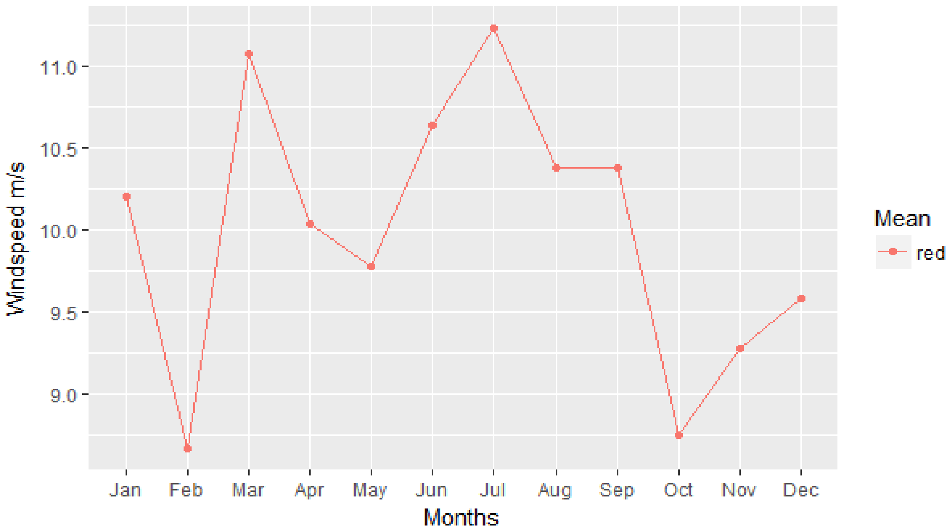

Figure-2. Variation of the mean annual wind speed for the six year period at 10 *m* height.

3.2 Effect of height on wind speed variation

Surface roughness coefficient for the site for each year calculated is shown in Table-1.

Table-1. Surface roughness coefficient values.

YEAR	Surface roughness coefficient (α)
2009	0.174
2010	0.171
2011	0.166
2012	0.160
2013	0.175
2014	0.170
Average	0.169

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The terrain has a characteristic of tall grass on level ground; this describes the terrain of the site in this study. The average roughness coefficient value is taken as 0.169 for calculating the speed of the wind at 100 m height. It was evident that the wind speed is directly proportional to the vertical height as could be seen from the calculated values at the height at 100 m in table 2 where the highest mean wind speed was 19.66 *m/s* on December 2011 as compared to 14.40 *m/s* of the same month and year at 10 *m* height.

Table-2. Monthly average wind speed values at 100 *m* height in *m/s*.

YYEAR	JJan	FFeb	MMar	AApr	MMay	JJun	JJul	AAug	SSep	OOct	NNov	DDec
22009	112.59	112.59	116.81	115.63	113.22	115.04	114.43	113.83	113.83	112.59	114.43	112.59
22010	113.83	111.96	117.40	116.81	115.63	113.22	117.97	111.96	112.59	114.43	113.83	113.22
22011	117.40	113.22	116.90	113.83	113.22	114.43	114.43	115.63	113.83	112.59	114.43	119.66
22012	115.04	111.96	116.81	113.83	116.81	116.81	117.40	118.54	116.23	117.40	113.83	115.04
22013	111.96	111.96	115.04	111.96	114.43	113.83	113.23	112.59	115.63	115.04	115.63	114.43
22014	118.54	116.81	112.59	116.22	113.23	119.11	119.11	117.97	118.54	66.51	110.80	99.81

3.3 Weibull parameters and density distribution

Table-3 shows the values of the, Weibull scale parameters *c*, shape parameters *k*, power density *P* and the model validation parameter *RMSE* at 10 m height level for the six years wind speed data.

Table-3. Yearly Weibull and performance parameters.

Year	**Vm** (m/s)	**C** (m/s)	**K**	**P** (W/m^2)	**RMSE**
2009	9.39	9.90	8.35	529.44	0.04
2010	9.78	10.51	6.03	630.74	0.02
2011	10.25	11.01	5.72	725.98	0.06
2012	10.98	11.63	8.69	859.52	0.02
2013	9.26	9.77	9.56	510.93	0.01
2014	10.33	11.49	3.68	869.58	0.04

Weibull scale parameter *c* varies between 9.77 *m/s* and 11.63 *m/s*thus were found to be generally higher than the shape parameter *k* which varies between 3.68 and 9.56. The annual power density has 510.93 W/m^2 as the minimum value and 869.58 W/m^2 as its highest value.

Weibull probability density distribution for wind speed data at 10 *m* height for each year is shown in Figure-3.

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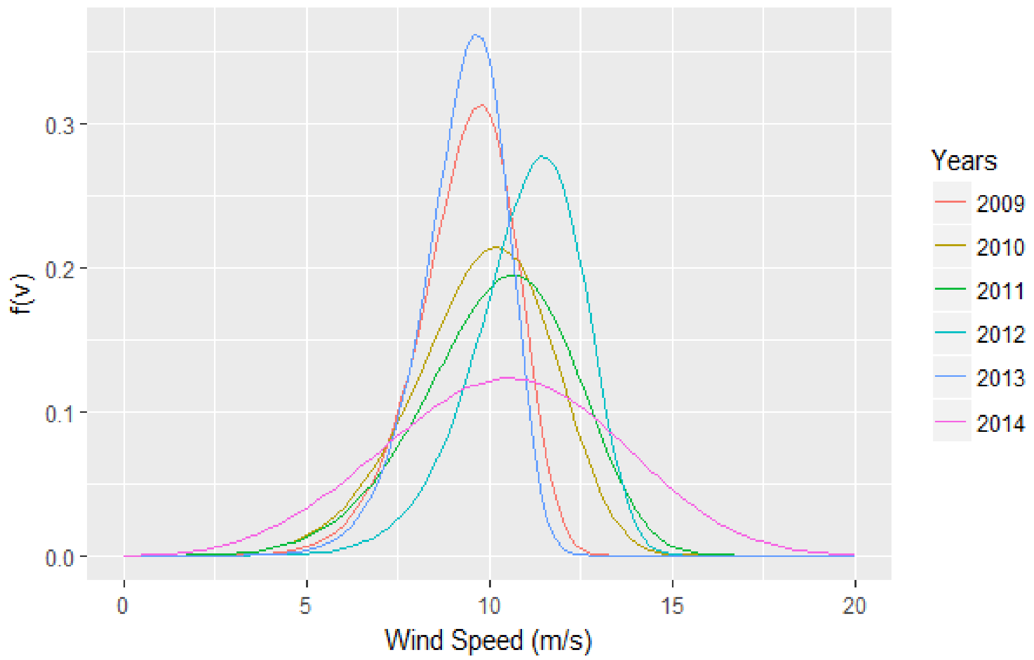

Figure-3. Yearly Weibull probability density distributions.

Year 2012 shows the highest peak value followed by year 2014 corresponding to high wind speeds with tapered distribution Years 2009 and 2013 have minimum and broad distribution corresponding to minimal wind speed distributions, year 2010 is transitional between the two limits.T he wind speed distribution for the purpose of this study has a best fit between 5 *m/s* and 12.5 *m/s.*

Weibull cumulative probability distribution for the wind speed data at the 10 *m* height for the years from 2009 - 2014 is shown in Figure-4.

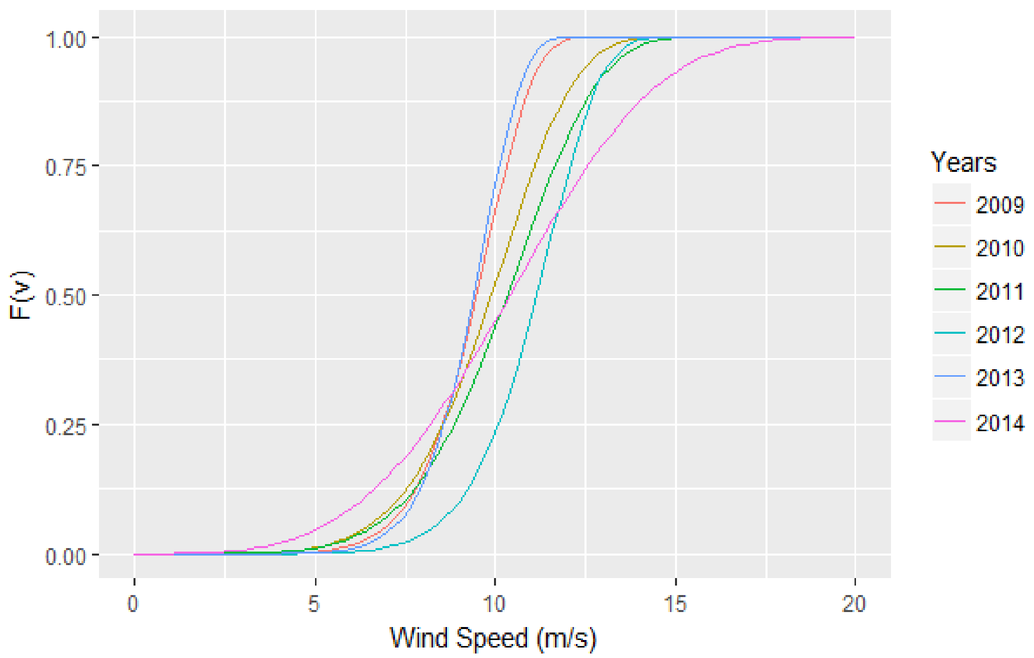

Figure-4. Yearly wind speed Weibull cumulated probability distribution.

It could be seen that at the cut in wind speed of 5 *m/s* the frequency spread is from 0% to 12.5%, at 7.5 *m/s* the frequency spread is from 2.5% to 18.75%, at wind speed of 10 *m/s* the frequency spread is from 25% to 75% and at the wind speed of 15 *m/s* the frequency spread of 93% to 100% were obvious.

3.4 Wind speed power density

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The six years (2009-2014) wind speed data based on the annual average depicting the monthly wind speed power density disparity is shown in Figure-5 at both 10 *m* and 100 *m* height levels.

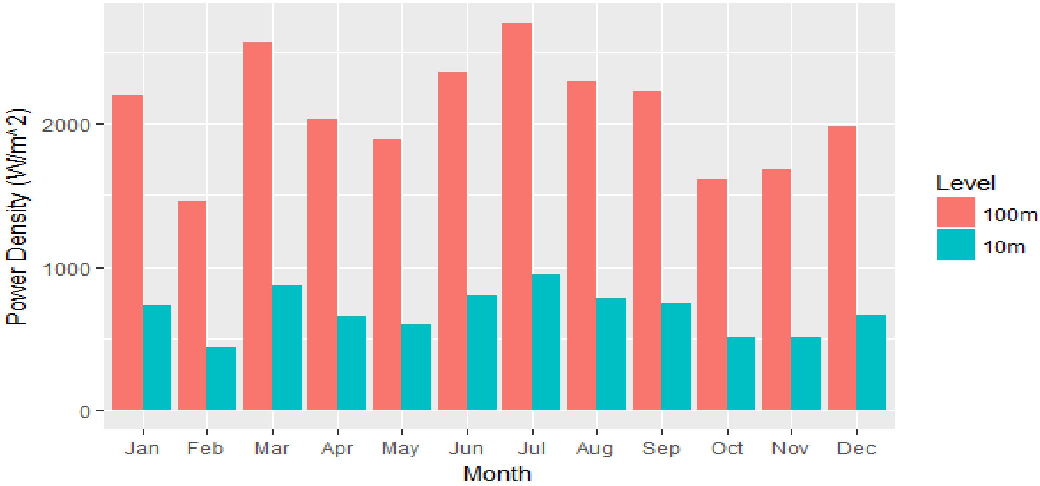

Figure-5. Monthly wind power density variation at heights 10 *m* and 100 *m* levels.

At both levels the months of February, October, and November had the minimum values of 440.03 W/m^2, 511.65W/m^2 and 512.97 W/m^2 respectively for the 10 *m* height and the values of 1455.46 W/m^2, 1608.82 W/m^2 and 1674.61 W/m^2 respectively at the height of 100 *m*. The highest power density were observed in the months of July and March with values of 947.26 W/m^2 and 874.32 W/m^2 at the height of 10 *m* while the values were 2704.88 W/m^2 and 2566.97 W/m^2 at 100 *m* level for the same period, the remaining months for the year fall within these range of values. It could be observed the value of the power density at 100 *m* height level roughly triple the power density values at 10 *m* height level and average power density for each month of the year.

Based on the National Renewable Energy Laboratory (NREL) wind data classifications, Kano Airport falls under areas designated above class 3 and therefore suitable for most utility-scale wind turbine applications. [21].

3.4.1 MODEL VALIDATION

The root mean square error *RMSE* as test of Goodness of fit indicated a successful validation of the Weibull model because *RMSE* should be close to zero for a good fit while a higher value shows a deviation. Table 3 shows the value obtained for the Weibull estimation varies between 0.01 and 0.06 which all tended towards zero.

4. CONCLUSIONS

The average monthly wind speed measured at height of 10 *m* level for the six year period data was moderately high throughout the year as could be seen from both minimum value of 8.66 *m/s* and maximum value of 11.23 *m/s* of the annual mean wind speed for the site. The site wind data under the period of study were analyzed using Weibull parameter model. The roughness coefficient average value of 0.169 calculated confirmed the site to be of tall grasses with wind break of over a kilometer. The average wind speed value was found increasing with increase in vertical height level. The year 2009 annual mean wind speed value of 9.39 *m/s* at 10 *m* height and13.96 *m/s* at 100 *m* height level is evident, additionally the Weibull scale *(c m/s)* parameter was however found to be higher than the Weibull shape *(k)* parameter both at 10 *m* height level and at 100 *m* height level. The Weibull probability density distribution for wind speed data at 10 *m* height for the period of years under analysis shows that the wind speed distribution for the purpose of this study is quite fit in between 5 *m/s* and 12.5 *m/s*. While the Weibull cumulative probability distribution for the wind speed data at the same height level and period of years indicated a cut-in wind speed of 5 *m/s* or less for wind turbines that might be recommended for the site. The power density of the wind speed data shows that the site under study is fit not only for the intended application but also for utility scale generation and the height of 50 m level will be more appropriate for the wind turbine generators.

Future studies of RES potential of the Kano Airport Nigeria should utilize other statistical methods other than the Weibull distribution methods to analyse the wind potentials of the area. Secondly, the solar PV energy potential of the Kano Airport needs to be investigated.

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