Ajayi, O.O.[1,*]; Fagbenle, R.O[2]; Katende, J[3]

[1] Mechanical Engineering Department, Covenant University, P. M. B. 1023, Ota, Nigeria
[2] Mechanical Engineering Department, Obafemi Awolowo University, Ile Ife, Nigeria
[3] Electrical and Information Engineering Department, Covenant University, Ota, Nigeria

* Corresponding author. Email: oluseyi.ajayi@covenantuniversity.edu.ng

Wind Profile Characteristics and Econometrics Analysis of Wind Power Generation of a Site in Sokoto State, Nigeria

Abstract: This study assessed the viability of wind electricity production at a local meteorological site in Sokoto State, Nigeria. 21 years monthly mean wind speed data at 10 m height obtained from the Nigerian meteorological station were employed to carry out monthly, seasonal, yearly and whole years wind profile characteristics. The data were subjected to the Weibull 2-parameter and other statistical analyses. The econometrics analysis of wind electricity generation from the site was also studied using three wind turbine models of AV 928, V90 and SWT-3.6-107. The outcome showed that the wind speed data ranged from 2.4 to 12.1 m/s while the modal wind speed range was from 6.9 to 9.0 m/s. 98% of the data were found to be greater than 3.0 m/s and better potential exist for wind power generation in the dry season than in the wet. It was also discovered that potential exist for electricity generation of between 60.0MWh and 1.5GWh per month and between 2.1 and 10.8GWh per annum. The least cost of generating 1kWh of wind electricity with the turbine models at the site is estimated to be € 0.014.

Key words: Wind power; Turbine cost; Cost per kWh; Weibull distribution; Sokoto; Nigeria

1. INTRODUCTION

Adequate and sustainable energy production has over the years been linked to economic development. However, the challenge of producing sufficient energy to meet both domestic and industrial needs has always been heightened by the concerns for the environment. Although the conventional sources of fossil fuel burning has been able to produce surplus amount of energy, its finite nature is a concern for the future. Employing environmentally friendly sources for energy production has gained wide acceptance across the globe. This is because these sources which include wind, solar and hydro contain sustained potentials for abundant energy generation. Generating electricity from these renewable energy resources requires first and foremost preliminary resource assessment

study. This is done to evaluate the potential and viability of producing electricity from the sources before investment procedure is undertaken. In the case of wind electricity production, the results of complete assessment study can aid in the selection of appropriate turbine model for a site. It can also be utilized in the determination of the wind profile characteristics of a site. Further to this, the results can be employed for the econometrics analysis of wind electricity generation from the turbine model selected. When this is done, wind energy investors will have pre-information about the quality of the required investment having known the viability and potential of the resources.

Various assessment studies on some sites in Nigeria have been done to ascertain the potential and viability of the sites' wind resources for electrical power generation [1-9]. Of particular interest to this study are the reports of two studies for sites located around Sokoto State [5, 10]. ECN-UNDP [5] simply reported that wind power of magnitude 97MWh/yr is capable of being generated at Sokoto. It however did not state how the study was conducted, what magnitudes of wind power were prevalent and the period of the study. This makes the result inconclusive and probably speculative. Also, ECN-UNDP [5] reported the outcome of wind mapping of Nigeria carried out by Lahmeyer International [10]. The work by Lahmeyer International [10] used 12 months wind speed data to determine the average wind speed for ten selected sites across the country. The result was then used to average for the nation. One of the sites is in Badaga, a place in Sokoto State. It reported that wind electricity of magnitudes 153.5, 358.8 and 1235.8 MWh/yr at heights 34.5, 42.0 and 44.0 m respectively are capable of being generated with two different turbine models installed at Badaga. The models are FL 250 and V52 made by Fuhrlander and Vestas respectively. This report is however limited in terms of accuracy. It is worthy of note that wind speed variation are location specific and associated with high variability in time and space. The outcome of ten stations' result is not sufficient to average for a nation as large as Nigeria. More so, the limited number of data points (12 months) is not sufficient. The monthly and seasonal variability of wind profiles characteristics across many years were not captured and hence the accuracy and applicability of the result is limited. Accurate results are based on historical data of many years. This work was therefore based on using 21 years' monthly mean wind speed data to evaluate the wind profile characteristics of a local meteorological site in Sokoto, Sokoto State, Nigeria. The result was further employed to determine the wind power potential and its viability for the site. The cost benefit analysis of wind electricity generation at the site was also carried out.

2. MATERIALS AND METHODS

The focus of this study was to analyze wind speed data of a local site (13.01 'N; 05.15' E; Altitude 350.8 m; Air density 1.1845 kg/m³) in Sokoto, Sokoto State, Nigeria to determine the monthly, yearly and seasonal wind profile characteristics. The potential of wind resources for power generation was also studied while the cost of generating wind electricity from the site was determined.

2.1 Data Source

The data employed for the study were monthly mean wind speeds obtained from the Nigerian meteorological department, Oshodi, Lagos state, Nigeria covering the period from 1987 to 2007. These were recorded continuously using cup-generator anemometer at a height of 10 m. Figs. 1 and 2 gives the 21 years' monthly and yearly average distribution of the mean speeds, while Figs. 3 and 4 presents the monthly and annual range of mean measured wind speed profiles across the period.
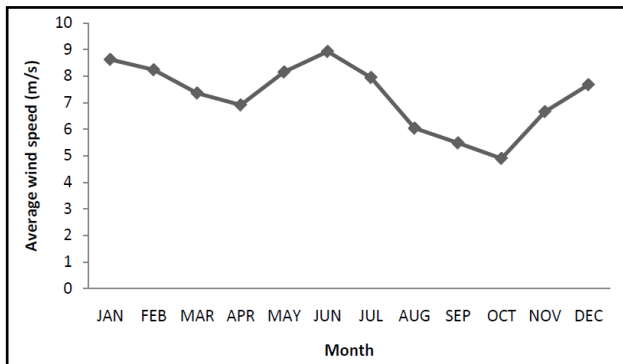

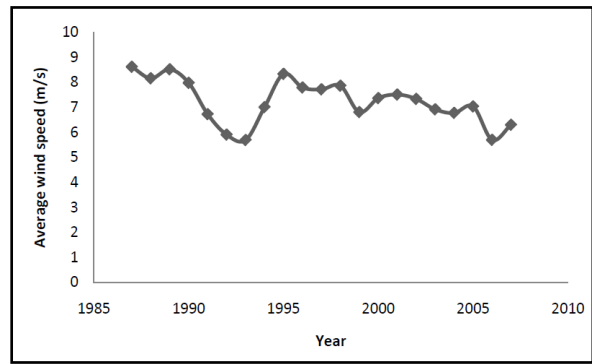**Fig. 1: Plot of 21 Years' Monthly Average Wind Speeds**

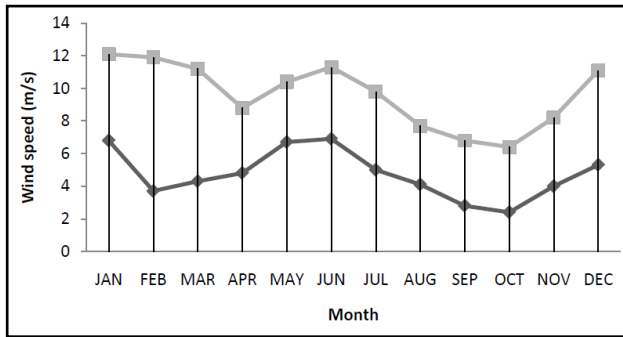**Fig. 2: Plot of 21 Years' Annual Average Wind Speeds**

Fig. 3: Plot Showing the Monthly Mean Measured Wind Speed Data Range
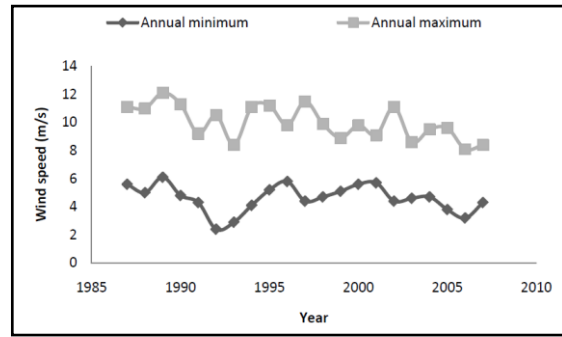

Fig. 4: Plot Showing the Yearly Mean Measured Wind Speed Data Range

2.2 Data Analyses

Of the various statistical distribution that could be employed for describing and analyzing wind resource data, the Weibull distribution has been found to be most adequate [8, 11]. Moreover, the 2-parameters Weibull statistical distribution has been proved to be more accurate than that of the 3-parameters. It can be employed in describing and predicting the characteristics of prevailing wind profile over a place [11-14]. This study therefore employed the 2-parameters Weibull Probability Density Function (PDF) with scale (c) and shape (k) being the parameters. The PDF is given as [8, 12]:

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

Where: $f(v)$ is the probability of observing wind speed v.

The corresponding Weibull Cumulative Distribution Function (CDF) is given as:

$$F(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{2}$$

Where: $F(v)$ is the cumulative distribution function of observing wind speed v.

However, the Weibull mean wind speed and standard deviation can be evaluated from equations 3 and 4:

$$v_m = c\Gamma\left(1 + \frac{1}{k}\right) \tag{3}$$

$$\sigma = \sqrt{c^2\left\{\Gamma\left(1 + \frac{2}{k}\right) - \left[\Gamma\left(1 + \frac{1}{k}\right)\right]^2\right\}} \tag{4}$$

Where Γ ( ) is the gamma function of ( ).

2.3   Validation of the Weibull Results

The accuracy of the Weibull results in the estimation of the wind speeds with respect to the actual values was evaluated using three statistical methods. These are the coefficient of determination, R^2, the Root Mean Square Error (RMSE) and the Nash-Sutcliffe model Coefficient Of Efficiency (COE) [15, 16]:

$$R^2 = \frac{\sum_{i=1}^{N}(y_i - z_i)^2 - \sum_{i=1}^{N}(x_i - y_i)^2}{\sum_{i=1}^{N}(y_i - z_i)^2} \tag{5}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2\right]^{\frac{1}{2}} \tag{6}$$

$$COE = 1 - \frac{\sum\limits_{i=1}^{N} (y_i - x_i)^2}{\sum\limits_{i=1}^{N} (y_i - \overline{x})^2} \tag{7}$$

Where: $y_i = i^{th}$ actual data, $x_i = i^{th}$ predicted data with the Weibull distribution = Weibull results, z = mean of the actual data and N = number of observations.

2.4 Goodness of Fit Test

The suitability of applying the Weibull distribution to the site's wind speed data was determined using the Kolmogorov–Smirnov (K-S) goodness of fit test according to Omotosho et al. [17]. Thus, the K-S statistical test based on a 95% significance level of α = 0.05 depicts the assumption that the two-parameter Weibull distribution is suitable at characterizing the wind speed profile of the site if P ≥ 0.05.

2.5 Estimation of Wind Power Density

The wind power density can be estimated from the Weibull parameters as:

$$p(v) = \frac{1}{2} \rho c^3 \left(1 + \frac{3}{k}\right) \tag{8}$$

where: $p(v)$ = wind power density (W/m^2) and ρ = air density at the site.

2.6 Evaluation of Useful Site Specific Wind Speeds

There are two wind speeds that are very useful to wind energy investors and assessors. These are called the most probable (v_{mp}) and maximum energy carrying (v_{Emax}) wind speeds. They are given in terms of the Weibull 2-parameters as:

$$v_{mp} = c \left(\frac{k-1}{k}\right)^{\frac{1}{k}} \tag{9}$$

$$v_{Emax} = c \left(\frac{k+2}{k}\right)^{\frac{1}{k}} \tag{10}$$

2.7 Simulating the Electrical Power Output from a Wind Turbine Model

At times it is important to determine the feasibility of employing wind turbine models in a site. To do this requires the ability to be able to predict the magnitude of power output that can be derived from such wind turbine models. Thus, the combination of Eq. 11 can be used to simulate the electrical power output from wind turbine models.

$$P_e = \begin{cases} 0 & (v < v_c) \\ P_{eR} \dfrac{v^k - v_c^k}{v_R^k - v_c^k} & v_c \leq v \leq v_R \\ P_{eR} & v_R \leq v \leq v_F \\ 0 & v > v_F \end{cases} \tag{11}$$

The average power output ($P_{e,ave}$) from the turbine which is related to the total energy production and also the total income/cost analysis can be evaluated from [18]:

$$P_{e,ave} = P_{eR} \left\{ \frac{e^{-\left(v_c/c\right)^k} - e^{-\left(v_R/c\right)^k}}{\left(v_R/c\right)^k - \left(v_c/c\right)^k} - e^{\left(v_F/c\right)^k} \right\} \tag{12}$$

The capacity factor (CF) associated with using a wind turbine to generate electricity is given as [18, 19]:

$$CF = \left\{ \frac{e^{-\left(v_c/c\right)^k} - e^{-\left(v_R/c\right)^k}}{\left(v_R/c\right)^k - \left(v_c/c\right)^k} - e^{\left(v_F/c\right)^k} \right\} \tag{13}$$

Where: P_{eR} = rated power electrical power, v_c = cut-in wind speed, v_R = rated wind speed and v_F = cut-out wind speed respectively of the model wind turbine.

In addition, three turbine models were employed for the study. These were the AV 928 (of Avantis Group), V 90 (of Vestas) and SWT-3.6-107 (of Siemens). The technical details of the turbines are presented in Table 1.

Tab. 1: Technical Data of Wind Turbine Models Used in the Analysis

Wind Machine	V_c (m/s)	V_F (m/s)	V_R (m/s)	P_{eR} (kW)	Hub Height (m)	Rotor Diameter (m)
AV 928	3	25	11.6	2500	80	93.2
V90	4	25	15	3000	80	90
SWT-3.6-107	3	25	13	3600	80	107

2.8 Econometrics Analysis of Electrical Generation from Practical Wind Turbines at the Sites

The econometrics analysis of wind generated electricity at the site was based on the simulation results of Eq. 12. Thus, the cost benefit analysis of generating certain magnitude of wind electricity for a particular period of the turbine life was evaluated from [20]:

$$C_{PV} = x\left(1+R_C\right) + \frac{x}{t}R_{om}\left[\frac{1+I_R}{R_I - I_R}\right] \times \left[1 - \left(\frac{1+I_R}{1+R_I}\right)^t\right] - xR_{sc}\left(1+R_C\right)\left(\frac{1+I_R}{1+R_I}\right)^t \tag{14}$$

Furthermore, the specific cost per kWh of wind electricity from the turbines can be evaluated from:

$$C_{SC/kWh} = \frac{C_{PV}}{\text{Annual } P_{e,ave} \times t} \tag{15}$$

where:

C_{pv} = present value cost, x = turbine price, R_C = rate chargeable on turbine price to arrive at the cost for civil/structural works, R_{om} = rate chargeable on annual turbine price to arrive at the cost for Operation and Maintenance, R_I = prevailing interest rate, I_R = prevailing inflation rate, R_{SC} = rate chargeable on total investment cost, t = turbine life or period of operation of turbine availability, $C_{SC/kWh}$ = specific cost per kWh of wind electricity.

Moreover, in carrying out the econometrics analysis of wind electricity generation at the site, certain assumptions were used. These assumptions are presented in Table 2.

Tab. 2: Assumptions Used for the Econometrics Analysis

Item	Assumed value
R_C	20%
R_{OM}	25%
R_I	6%
I_R	12%
R_{SC}	10%
t	20 years

3.   RESULTS AND DISCUSSION

Analysis of the whole data spread revealed that the site's wind speeds ranged between 2.4 and 12.1 m/s across the period of consideration. Figs. 1 and 2 however, present the average monthly and annual wind speed profiles covering the period between 1987 and 2007. Analyses of Figs. 1 and 2 revealed that the 21 years monthly average wind speeds ranged between 4.9 in October and 8.9 m/s in June. While the yearly average wind speeds ranged between 5.7 in 1993 and 8.6 m/s in 1987. When Fig. 1 was compared with Fig. 2, more variability was found to be associated with the monthly average data than those of annual data. Moreover, the range of mean measured wind speeds (Figs. 3 and 4) across the period revealed that almost all the data spread are values above 3.0 m/s. The frequency of occurrence of the wind speed data are presented in Fig. 5.
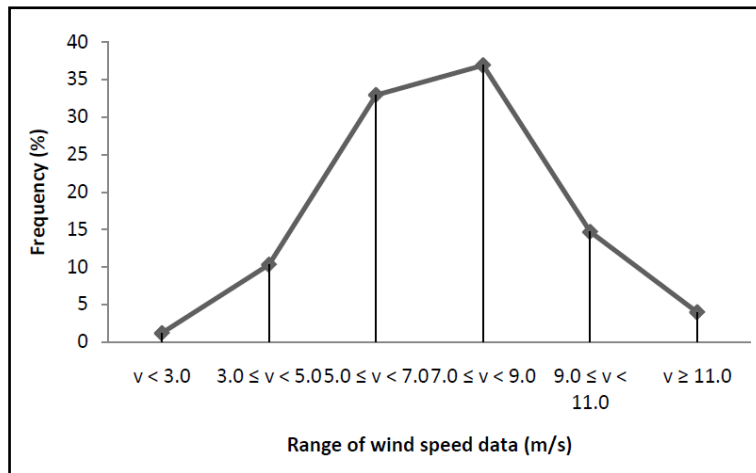

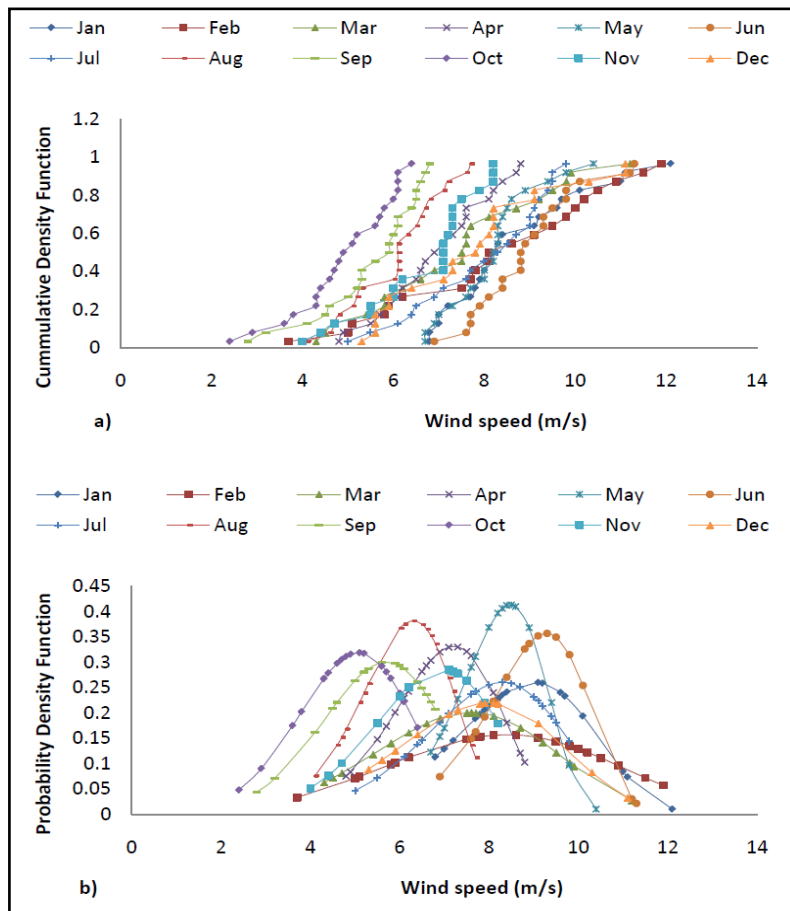**Fig. 5: Plot of Frequency of Occurrence of Wind Speed Data Range**

Fig. 6: Plots of Monthly (a) CDF and (b) PDF from the Weibull Analysis

Fig. 5 revealed that of the 252 wind speed data, only 3 (1.2%) were values below 3.0 m/s. 88.5% of the data were values from 5.0 to 12.1 m/s. The modal wind speed range lay between 6.9 and 9.0 m/s. Moreover, since most new wind turbine designs can operate with cut-in wind speed of 3.0 m/s, the data values indicates that the site has potential for wind electricity generation.

Tab. 3: Some of the Results of the Weibull Analysis

Period	$V_{weibull}$ (m/s)	k (-)	c (m/s)	$\sigma_{weibull}$ (m/s)	σ_{actual} (m/s)	P_w (W/m^2)
JAN	8.6	6.5	9.3	1.6	1.5	709.6
FEB	8.2	3.7	9.1	2.5	2.3	838.6
MAR	7.4	4.3	8.1	1.9	1.9	550.0
APR	6.9	6.6	7.4	1.2	1.2	361.2
MAY	8.1	9.6	8.6	1.0	1.0	506.7
JUN	8.9	9.1	9.4	1.2	1.1	677.9
JUL	7.9	6.0	8.6	1.5	1.4	576.2
AUG	6.0	6.6	6.5	1.1	1.0	239.6
SEP	5.5	4.8	6.0	1.3	1.1	214.6
OCT	4.9	4.5	5.4	1.2	1.1	157.3
NOV	6.7	5.5	7.2	1.4	1.3	354.1
DEC	7.7	4.9	8.4	1.8	1.8	578.5
Dry Season	7.2	4.1	8.0	2.0	2.1	538.1
Wet Season	7.2	5.0	7.9	1.7	1.7	478.5
Whole Year	7.2	4.5	7.9	1.8	1.9	505.8
1987	8.6	5.8	9.3	1.7	1.6	746.2
1988	8.1	4.5	8.9	2.0	1.9	721.8
1989	8.5	4.7	9.3	2.1	2.0	805.0
1990	8.0	3.6	8.9	2.5	2.4	781.0
1991	6.7	5.2	7.3	1.5	1.4	375.9
1992	5.9	2.5	6.7	2.6	2.5	408.3
1993	5.7	3.6	6.3	1.8	1.7	285.2
1994	7.0	3.9	7.7	2.0	1.9	501.6
1995	8.3	5.2	9.0	1.8	1.7	714.5
1996	7.8	6.9	8.3	1.3	1.2	503.8
1997	7.7	4.6	8.5	1.9	1.7	610.2
1998	7.9	4.2	8.6	2.1	1.9	675.5
1999	6.8	6.0	7.3	1.3	1.2	360.9
2000	7.4	5.5	8.0	1.5	1.4	478.6
2001	7.5	6.2	8.1	1.4	1.3	476.4
2002	7.3	4.6	8.0	1.8	1.7	521.3
2003	6.9	5.5	7.5	1.5	1.3	396.2
2004	6.8	5.0	7.4	1.5	1.5	390.6
2005	7.0	4.1	7.7	1.9	1.8	491.7
2006	5.7	3.3	6.4	1.9	1.8	300.0
2007	6.3	4.0	7.0	1.8	1.6	363.9

Seasonally, Figs. 1 and 3 clearly demonstrated that the site has a better wind speed profile in the dry season (October to March) than in the wet (April to September). The data range between the dry and wet periods were found to lie within 2.4 to 12.1 m/s and 2.8 to 11.3 m/s respectively.

Statistical Weibull analysis of the site's wind speed data gave results of Table 3 while the monthly, seasonal and whole year's CDF and PDF plots are presented in Figs. 6 and 7. Figs. 6a and 7a shows that the wind speed profiles for the periods follow the same cumulative distribution pattern. The difference in shapes of the CDF and PDF plots were the results of the varying values of k and c as shown in Table 3.
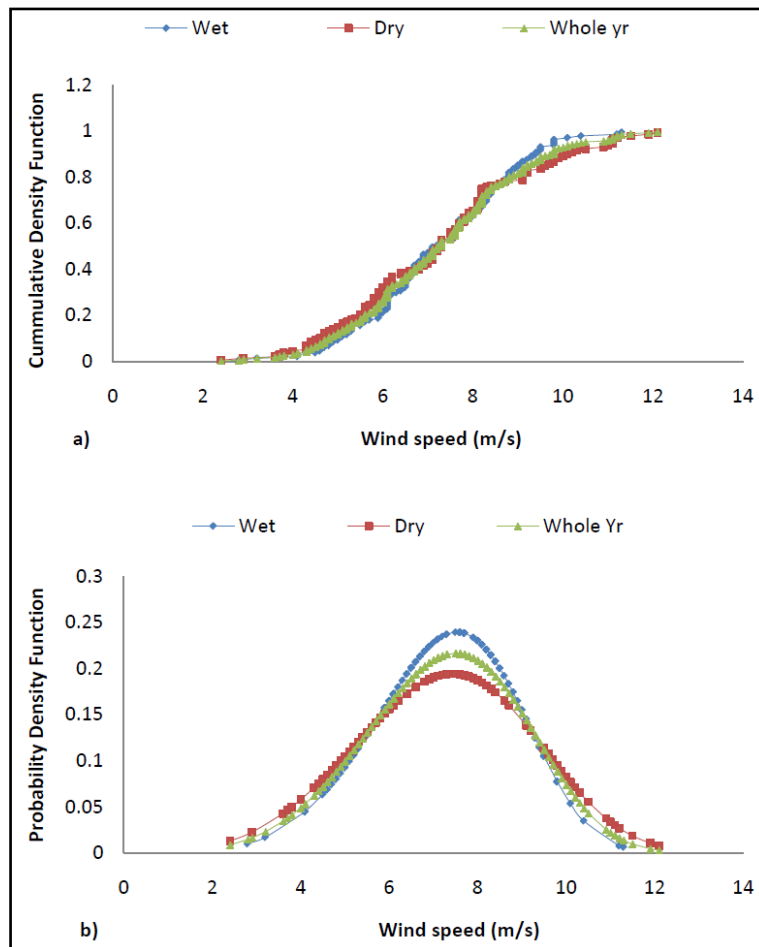

Fig. 7: Plots of Seasonal and Whole Year (a) CDF and (b) PDF from the Weibull Analysis

Fig. 6a revealed that 50% of the data series were values that ranged from about 4.9 to 8.8 m/s and below, while 80% of the data series were values that ranged from about 6.1 to 10.5 m/s and below. Also, the seasons' Weibull plots revealed that 50% of the wet season's data series were values that ranged from 2.8 to 7.2 m/s, while for dry it ranged from 2.4 to 7.3 m/s. More so, 80% of the wet season's data ranged from 2.8 to 8.8 m/s, while for dry it ranged from 2.4 to 9.1 m/s. To establish the reliability and adequacy of the Weibull results, Eqs.5 to 7 were used together with the K-S statistics and the results are presented in Fig. 8.

Fig. 8 reveals that results of the K-S statistical analysis gave P > 0.05 across the periodic and yearly analyses. This indicates that the Weibull distribution is adequate at characterizing the site's wind speed profiles. Also, the reliability test results gave $0.86 \leq R^2 \leq 0.99$ and $0.87 \leq COE \leq 0.99$. Based on the statistical interpretation that the Weibull predicted result is adjudged accurate if the estimated values of R^2 and COE are close to 1, the results obtained can be described as accurate. The values of RMSE, which were $0.14 \leq RMSE \leq 0.58$, further corroborate the acceptance of the Weibull results. Fig. 9 showed that the Weibull results accurately predict the measured data.
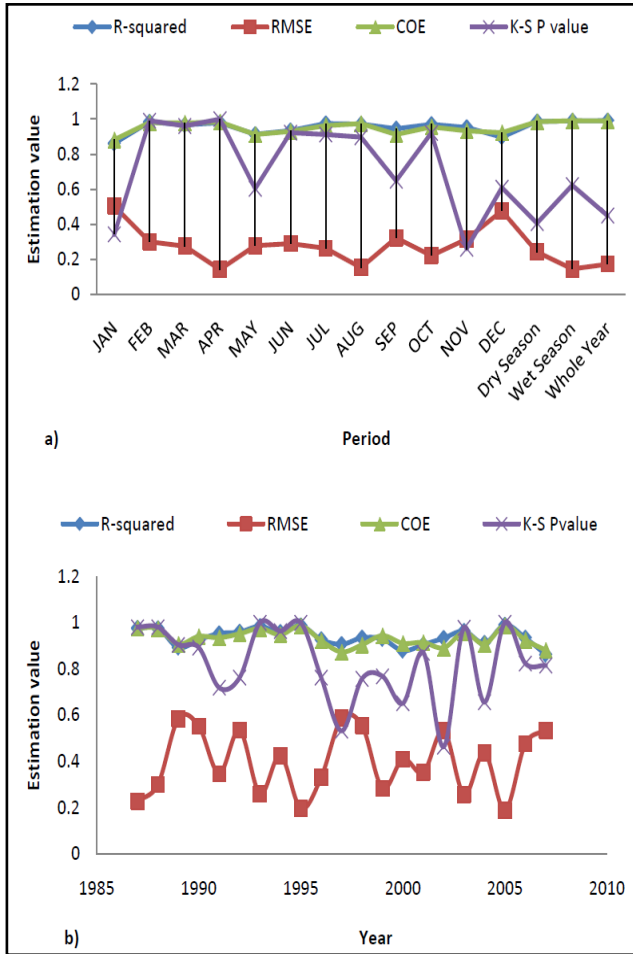
Fig. 8: **Estimation Parameters of the Weibull Statistical Distribution for (a) Periodic Analyses (b) Annual Analyses**
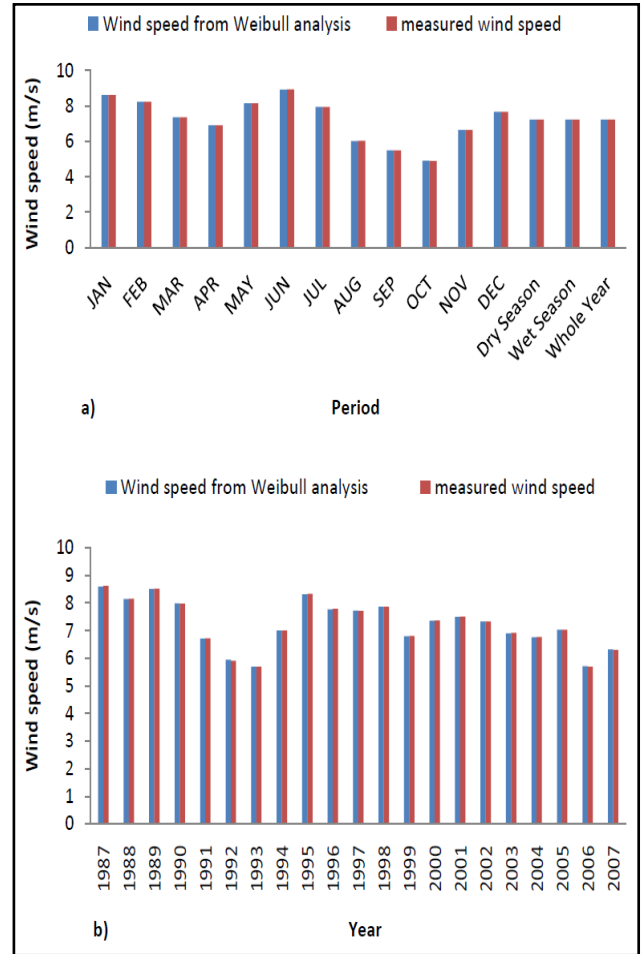
Fig. 9: **Plots Showing the Degree of Convergence of the Weibull Wind Speed Results to the Measured Wind Speeds for (a) Periodic Analyses and (b) Annual Analyses**

Furthermore, two wind speeds of utmost interest to wind resource assessors are the wind speed carrying maximum energy (v_{Emax}) and the most probable wind speed (v_{mp}). The knowledge of these wind speeds aid in the determination of the wind speed rating of a suitable wind turbine for a particular site. The results of the most probable (v_{mp}) and maximum energy carrying wind speeds (v_{Emax}) analyses for the periods and years are presented in Fig. 10. It showed that the values of v_{mp} and v_{Emax} from January to December ranged from 5.1 to 9.3 m/s for v_{mp} and 5.8 to 10.2 m/s for v_{Emax} respectively. Annually the values of v_{mp} and v_{Emax} ranged from 5.4 to 9.0 m/s for v_{mp} and 7.2 to 10.0 m/s for v_{Emax} respectively.

3.1 Modelling Wind Profile Characteristics of the Site

Earlier it was proved by the K-S test results that the 2-parameter Weibull statistical distribution is adequate at predicting and characterizing the site's wind speed profiles. More so, the Weibull probability density function according to Carta et al. [11] is relevant for the statistical analysis of wind characteristics and wind power density. It is also useful in the estimation of the energy output and capacity factor of wind turbines and in the analysis of performance of the autonomous wind energy systems [8, 11, 18]. Therefore, simple models that can approximate the Weibull parameters without the associated computational and repetitive procedure of Eqs.1 to 4 can be useful. These models can be made much more useful if they establish the relationship between the actual data and the Weibull results of c, k, $\bar{v}_w$ and σ_w. Thus, once the actual mean measured wind speed, $\bar{v}$, is known, the Weibull results can be evaluated for each data point. In order to establish these models, this study employed the statistical

regression analysis to develop the models. It also used the coefficient of determination and the Mean Square Error (MSE) to evaluate the degree of accuracy of the models. The obtained models are:

$$\bar{v}_w = 0.997\bar{v} + 0.016 \, (R^2 = 1.0; \, MSE^1 = 0.43E\text{-}5) \tag{16}$$

$$c = -0.03\bar{v}^2 + 1.47\bar{v} - 1.15 \quad (R^2 = 0.990; \, MSE = 0.0152) \tag{17}$$

$$k = 4.67252 - 12.872c + 14.085\bar{v}_w \quad (R^2 = 0.974; \, MSE = 0.0720) \tag{18}$$

$$\sigma_w = 0.953 - 0.218k + 0.234c \quad (R^2 = 0.954; \, MSE = 0.0069) \tag{19}$$

The wind power according to Weibull analysis can therefore be evaluated using Eq. 8 after substituting the values of c and k. The values of R^2 and MSE for each equations presented above demonstrate that these mathematical models are suitable for evaluating the Weibull parameters with minimal error.

4. WIND TURBINE ELECTRICITY GENERATION AND ECONOMETRICS ANALYSES

Installing a wind turbine at a site for electricity generation is capital intensive. More so, selecting the right wind turbine for the site will depend on the prevailing location's wind profile characteristics. Thus, preliminary analysis to determine and forecast the magnitude of electrical power that a particular wind turbine will likely generate is a necessity. This invariably involves the application of different turbine models to the site's wind profile data. In order to do this, Eqs.11 to 13 can be used with different turbine models to evaluate the electrical power output that can be generated from the turbine. Three turbine models with technical details presented in Table 1 were employed for the study. Moreover, because the turbine hub heights are at 80 m, it was necessary to determine the wind profile characteristics at this height.   This was estimated from [21]:

$$v_{ref} = v_{10}\left(\frac{h_{ref}}{h_{10}}\right)^\alpha = \left(\frac{80}{10}\right)^\alpha = v_{10}(8)^\alpha = v$$

where:

$v_{ref} = v_{80}$ = wind speed at 80 m, v_{10} = wind speed at 10 m height, h_{ref} = reference height = 80 m, h_{10} = 10 m height, α = roughness factor for the sites. The commonest and widely accepted value of α for most sites is 0.143.

The results of Weibull statistical analysis for wind speed at 80 m height were then used with Eqs.11 to 13 and the outcome is presented in Table 4

In terms of the capacity factor, Table 5 shows that turbine model AV 928 will produce at the highest CF across the months and years. This was due to the fact that, the speed rating of the model fell adequately within the site's wind speed data range at 80 m height. Model V 90 has the lowest CF. The wind speed data range at 80 m height was estimated to be from 3.2 to 16.3 m/s. However, in terms of the average power output, model SWT-3.6-107 was the best and closely followed by AV 928. This was partly due to the wind speed range at the hub height being close to the model's speed rating. Another reason is the fact that, for every speed value greater than the cut-in wind speed, it has higher potential of producing better magnitude of wind power than AV 928. As a result of the speed rating of model V 90, it gave the lowest average power across the months and years. Thus based on the site's wind profile characteristics, SWT-3.6-107 is the best of the three turbine models, even though AV 928 is most efficient for the site.

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[1]   The reported values of the MSE are the maximum obtained for monthly, seasonal, yearly and whole years' analyses

Tab. 4: Results from Simulating Electrical Power Output with the Wind Turbine Models

| Period | AV 928 | | | V 90 | | | SWT-3.6-107 | | |
	Pe (kW)	PeAve (kW)	CF (%)	Pe (kW)	PeAve (kW)	CF (%)	Pe (kW)	PeAve (kW)	CF (%)
Jan	3022.51	1524.54	60.98	2203.80	1464.53	48.82	3475.92	2028.50	56.35
Feb	2185.80	1730.80	69.23	957.05	1237.90	41.26	1984.80	2061.60	57.27
Mar	1314.58	1414.18	56.57	499.91	738.96	24.63	1120.02	1481.41	41.15
Apr	614.17	898.78	35.95	128.29	203.61	6.79	395.31	624.60	17.35
May	1579.19	1603.88	64.16	149.20	244.85	8.16	703.82	1103.84	30.66
Jun	3666.11	2043.91	81.76	395.81	640.50	21.35	1737.68	2040.28	56.67
Jul	1610.78	1586.61	63.46	395.56	615.66	20.52	1116.51	1526.37	42.40
Aug	247.46	392.03	15.68	50.73	80.74	2.69	158.23	251.11	6.98
Sep	298.30	454.42	18.18	96.42	149.75	4.99	238.79	365.35	10.15
Oct	196.67	300.01	12.00	65.37	102.88	3.43	162.40	247.80	6.88
Nov	631.11	903.67	36.15	173.39	270.32	9.01	462.14	713.23	19.81
Dec	1477.82	1510.88	60.44	480.55	723.72	24.12	1168.14	1547.25	42.98
1987	2912.10	1155.17	46.21	2389.33	1111.07	37.04	3539.07	1550.85	43.08
1988	2015.62	1704.15	68.17	717.94	1018.45	33.95	1661.16	1911.71	53.10
1989	2458.25	1821.65	72.87	836.57	1152.34	38.41	1982.03	2100.18	58.34
1990	1959.25	1659.54	66.38	886.32	1165.90	38.86	1808.54	1958.52	54.40
1991	718.26	990.73	39.63	215.75	333.85	11.13	548.51	833.31	23.15
1992	966.48	1103.66	44.15	542.43	751.36	25.05	1018.26	1278.33	35.51
1993	574.83	797.31	31.89	250.67	377.00	12.57	533.61	774.87	21.52
1994	1145.44	1303.59	52.14	475.02	698.05	23.27	1019.26	1368.23	38.01
1995	2178.76	1761.81	70.47	658.64	962.32	32.08	1662.78	1932.45	53.68
1996	1300.66	1452.44	58.10	246.60	393.09	13.10	799.75	1199.21	33.31
1997	1570.12	1545.77	61.83	549.61	812.15	27.07	1284.69	1639.78	45.55
1998	1759.40	1611.91	64.48	675.56	961.37	32.05	1503.17	1794.50	49.85
1999	633.83	913.84	36.55	153.81	241.85	8.06	437.63	683.04	18.97
2000	1099.33	1312.11	52.48	302.98	470.68	15.69	804.66	1179.55	32.77
2001	1112.42	1331.40	53.26	255.39	402.47	13.42	747.63	1122.27	31.17
2002	1232.49	1377.01	55.08	429.06	646.61	21.55	1007.00	1382.09	38.39
2003	776.65	1053.93	42.16	214.59	334.14	11.14	569.76	869.61	24.16
2004	772.50	1041.40	41.66	240.63	371.03	12.37	600.06	902.82	25.08
2005	1117.55	1292.23	51.69	440.31	654.15	21.81	969.99	1325.77	36.83
2006	632.87	854.56	34.18	290.55	433.49	14.45	603.18	861.02	23.92
2007	744.55	989.22	39.57	299.57	450.54	15.02	656.72	951.84	26.44

4.1 Econometrics analysis

This is estimated from Eqs.14 and 15 based on the assumptions presented in Tables 2 and 5.

Substituting the assumptions of Table 2 into Eq. 14 gives:

$$C_{PV}=1.30755x \tag{19}$$

Tab. 5: Assumed Turbine Model Price

Turbine model	Assumed price (€)
AV 928	2,500,000
V90	3,000,000
SWT-3.6-107	3,500,000

Therefore, Eq. 20 can be used with the turbine prices to determine the present value cost. The outcome of the analysis is presented in Table 6. Further to this, the specific cost of generating 1kWh of electricity was evaluated from present value cost and average annual power output. The result is also presented in Table 6.

Tab. 6: Econometrics Analysis for Wind Electricity Production

Turbine model	Present value cost	Average $P_{e,ave}$ per annum (from Table 5) $\times 10^6$ kWh	20 years average $P_{e,ave}$ (t $\times P_{e,ave}$) $\times$ 10^6 kWh	Specific cost per kWh (€)	Specific cost per kWh (Nigeria naira)
AV 928	3,268,875	11.3	226	0.014	3.08
V90	3,922,650	5.7	114	0.034	7.29
SWT-3.6-107	4,576,425	11.5	230	0.020	4.24

Table 6 shows that the turbine model that can produce the cheapest electricity for the sites is model AV 928. However, considering the advantage model SWT-3.6-107 had in terms of its potential for higher power output, economic decision would need to be made before conclusion is reached. Such decision would be based on either to compromise the potential for higher power output and embrace the choice of lowest cost of power and vice versa.

5. CONCLUSION

The study was used to assess the wind power resource potential of a local meteorological site in Sokoto, Nigeria. Monthly wind speed data obtained from the Nigeria meteorological agency for the site were analyzed with 2-parameter Weibull probability density function. The outcome gave the following conclusion:

a) The 2-parameter Weibull statistical distribution is adequate for characterizing the site wind speed profile.

b) The monthly Weibull parameters k and c (m/s) were estimated to lie within the range $3.7 \leq k \leq 9.6$ and $5.4 \leq c \leq 9.4$ respectively.

c) The estimated range of yearly Weibull parameters k and c (m/s) lay within the range $2.5 \leq k \leq 6.9$ and $6.3 \leq c \leq 9.3$ respectively.

d) The values of the Weibull parameters showed that there is good uniformity with relatively small scatter in the site's wind speed data spread.

e) A wind turbine model with wind speed rating of cut-in and cut-out speeds of 3.0 and between 12 and 16 m/s respectively is suitable for the site.

f) The econometrics analysis showed that it is possible to generate a kWh of wind electricity with € 0.014.

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