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Analytical Predictive Model for Wind Energy Potential Estimation: A Model for Pre-assessment Study

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Abstract: The study was used to develop a model that can be employed to carry out a pre-assessment study of a potential site for wind farm establishment. It made use of 21 years (1987-2007) monthly mean wind speeds from 11 stations spread across the South-West geopolitical zone of Nigeria. The data were assessed from the nation's meteorological department, Oshodi Lagos. These were then statistically analyzed to develop a model that could predict the likelihood of a site's capacity for wind farm development. The model could also serve as a pointer to predicting the likely range of wind energy magnitude that can be generated from a site. Further to this, the results obtained from employing the model were compared with those obtained from the well established 2-parameter Weibull statistics and found to be good enough. Thus the model, if employed can serve as a first stop for wind energy investor to make decision on a potential site before comprehensive site assessment study is embarked upon.

Key words: Weibull, modelling, wind power and energy, Nigeria

INTRODUCTION

Wind as a source of electrical energy is growing in popularity across the globe (Babainejad and Keypour, 2010; Abdelaziz *et al*., 2011; Yasin *et al*., 2011; Yu *et al*., 2012). However, its development and utilization in developing countries, particularly Africa, has been hindered by absence of adequate measurements and/or assessment studies to ascertain its potential viability for power generation (Ajayi *et al*., 2011a). This according to Ajayi *et al*. (2011a) has hindered national and international wind energy investors from embarking on wind energy technology development and establish wind farms across the countries. Moreover, generating electricity from wind requires the first step of detailed and rigorous resource assessment. This is done to ascertain the magnitude of potential and the viability of developing a wind farm in the site/location of interest. Further to this, the result of complete assessment study can aid in the selection of appropriate turbine model for a site. It can also be employed for determining the site's wind profile characteristics and economic benefits of generating wind electricity from the site (Ajayi *et al*., 2011b). It is worthy of note that, before embarking on wind energy investments, the investor would first like to know where a certain wind speed is possible and what would be the corresponding energy output from such speed.

Moreover, various models exist for analyzing wind speed data for power generation. Some of those that have been used in time past range from using standard parametric distributions to distributions that relate to applying the principle of maximum entropy. Some authors have also suggested the use of univariate and bivariate distributions, unimodal, bimodal, bitangential and hybrid distributions (Justus, 1978; De Auwera *et al*., 1980; Koeppl, 1982; Ozerdem and Turkeli, 2003; Shata and Hanitsch, 2006; Penelope and Carta, 2006; Akpinar and Akpina, 2007; Tar, 2008; Chang and Tu, 2007; Shamilov *et al*., 2008; Carta *et al*., 2009). In the recent past, better statistical models have surfaced. These include the gamma distribution function of two parameters, normal and lognormal, Rayleigh and Weibull statistical distributions (Ozerdem and Turkeli, 2003; Akpinar and Akpina, 2007; Ngala *et al*., 2007; Carta *et al*., 2009).

According to Carta *et al*. (2009), the Rayleigh distribution function of one parameter corresponds to the chi distribution for two degrees of freedom and also coincides with the two parameter Weibull distribution when the shape parameter (k) of the latter takes the value 2. Moreover, the Weibull distribution technique has enjoyed more emphasis. It has been employed in various regions of the world fundamentally to evaluate wind energy potential and carry out the complete statistical analyses of wind characteristics (Akpinar and Akpinar,

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2005a, b; Fadare, 2008; Yang *et al*., 2008; Carta *et al*., 2009; Kamau *et al*., 2010; Fagbenle *et al*., 2011; Ajayi *et al*., 2011a, b). Further to this, the Weibull two-parameter distribution (scale (c) and shape (k) parameters) has also always provided results with the best goodness-of-fit and statistical significance (Burton *et al*., 2001; Akpinar and Akpinar, 2005a, b; Kwon, 2010).

However, the use of these models, especially the Rayleigh and Weibull distributions involve the utilization of a set of wind speed data covering some period for statistical significance. Based on this, some investors may be unwilling to commit resources to embark on this task since they are not sure of the outcome. This therefore creates a need for the development of an empirical model that can be used as a first stop before complete assessment study. Such model when available will aid in site selection. In addition, although such pre-assessment model may not give accurate results but could lead to the determination of the likely potential of wind energy harvest of a site/location. This is the focus of this study. It aims to use existing equations to develop a better but simple model representation that is suitable for evaluating the likelihood potential of a site. The result from this model will serve as a pointer to determining the likelihood of generating what magnitude of wind electricity (either gigawatt-hour (GWh), megawatt-hour (MWh) or kilowatt-hour (kWh)).

MATERIALS AND METHODS

A complete assessment study begins with site selection and preparation, followed by installation of wind speed measuring equipment. In order to have adequate measurement and statistically significant analysis, wind speed measurements covering some years are always required. This is done in order to capture the associated fluctuations of wind speeds across a location. Figure 1 presents a flowchart showing the steps to complete resource assessment and decision making. The analysis and modelling stage is critical to the study as it exposes the site's potential and determines the degree of viability of wind-to-power project at the site.

Moreover, for the purpose of this study, monthly mean wind speeds at 10 m height covering 21 years (1987 to 2007) were obtained from the Nigerian meteorological department, Oshodi, Lagos State, Nigeria. The data are statistically presented using Fig. 2 to 10 for both monthly and annual distributions. The distributions of Fig. 2 and 3 were obtained by evaluating the 21 years' arithmetic mean of the wind data across the months and years. Those of Fig. 4 to 8 were obtained by determining the period's lowest and highest mean wind speed values of the data lot across each month. Figure 9 and 10 on the other hand is used to represent the range of data spread across the period of months and years. The information regarding the stations' location of which the wind speed data were employed is presented in Table 1.

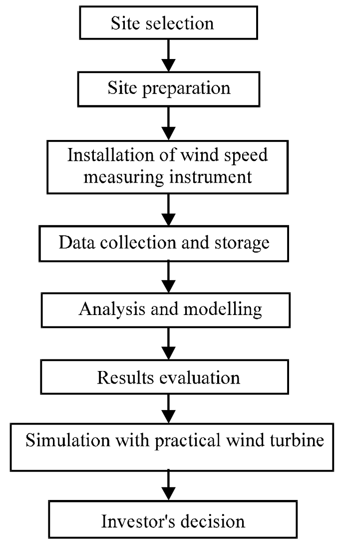

Fig. 1: Step by step procedure for carrying out complete resource assessment study

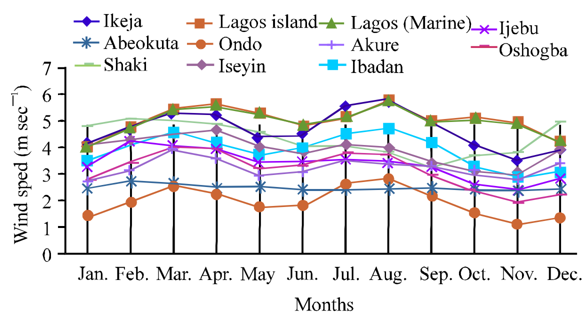

Fig. 2: Twenty one years' monthly average wind speed profiles for all the stations

Table 1: Details of the stations for which wind data were assessed

Station	Latitude (N)	Longitude (E)	Altitude (m)	Air density (kg m^{-3})
Ikeja	6.35	3.20	39.4	1.22
Lag. island	6.27	3.24	14.0	1.22
Lag. marine	6.26	3.25	2.0	1.22
Abeokuta	7.10	3.20	104.0	1.213
Ijebu Ode	6.50	3.56	77.0	1.216
Akure	7.17	5.18	375.0	1.182
Ondo	7.06	4.50	287.3	1.192
Oshogbo	7.47	4.29	302.0	1.19
Ibadan	7.26	3.54	227.2	1.199
Iseyin	7.58	3.36	330.0	1.187
Shaki	8.40	3.23	457.0	1.17

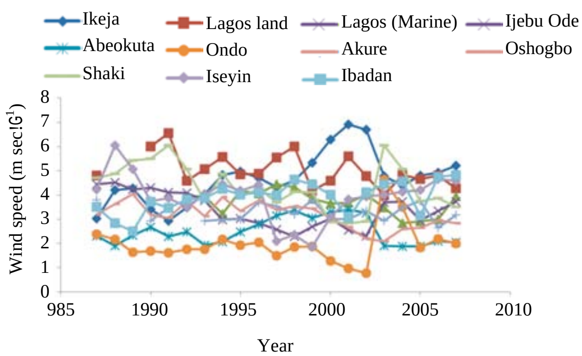

Fig. 3: Twenty one years' annual average wind speed profiles for all the stations

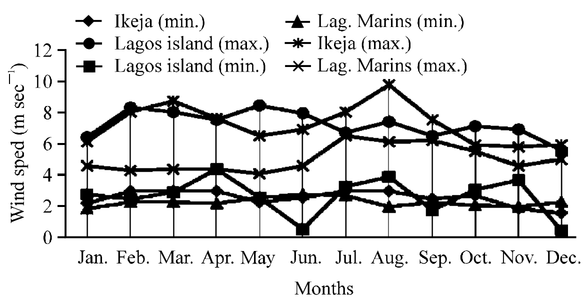

Fig. 4: Wind profiles showing monthly mean wind speed range for stations in Lagos state

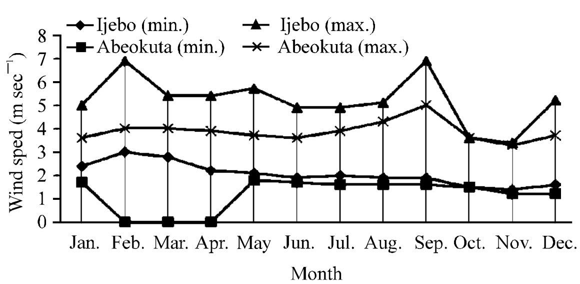

Fig. 5: Wind profiles showing monthly mean wind speed range for stations in Ogun state

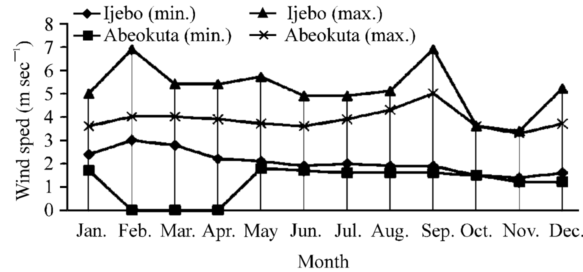

Fig. 6: Wind profiles showing monthly mean wind speed range for stations in Ondo state

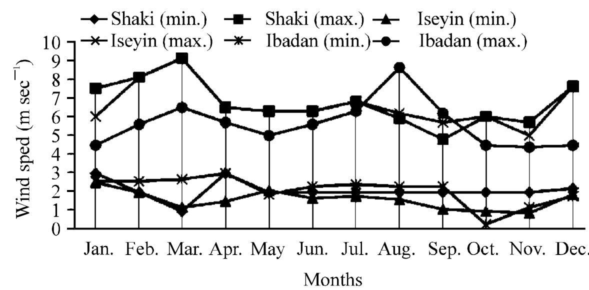

Fig. 7: Wind profiles showing monthly mean wind speed range for stations in Oyo state

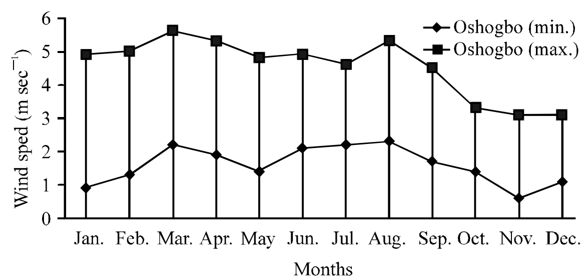

Fig. 8: Wind profiles showing average monthly mean wind speed range for stations in Osun state

Modelling procedure

Wind power: The average power extractable from the wind by a wind turbine has been established to vary with the cube of the average wind speed of a local site. This is given mathematically as:

$$P = \frac{1}{2}\left(A\rho C_p \frac{1}{x}\sum_{i}^{x} v_i^3\right) \quad (1)$$

Where:

P = Power flux
ρ = Air density
v_i = Wind speeds
C_p = Coefficient of power
x = Number of data points
A = Wind turbine rotor area

Wind power evaluated from the Weibull statistics is derived from Akpinar and Akpinar (2005a, b) and Fagbenle *et al*. (2011):

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

where, p (v) is wind power from Weibull distribution, c and k are the Weibull scale and shape parameters, respectively.

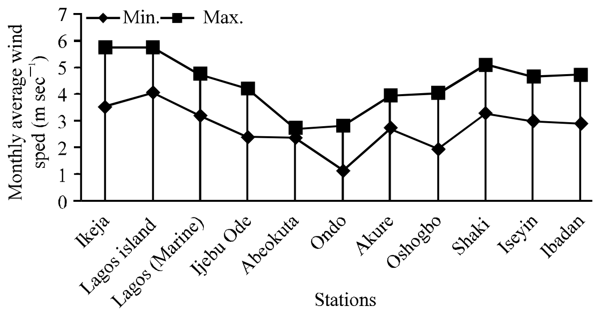

Fig. 9: Twenty one years' monthly average wind speed range for each of the stations

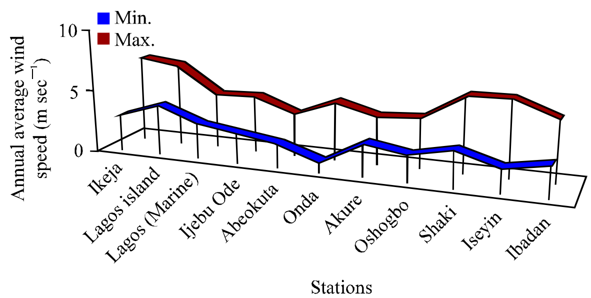

Fig. 10: Twenty one years' annual average wind speed range for each of the stations

The Weibull mean wind speed and standard deviation are generated from Ajayi *et al*. (2011a):

$$v_{weibull} = c\Gamma\left(1+\frac{1}{k}\right) \quad (3)$$

where, Γ ( ) is the gamma function of ( ).

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

Estimation of the performance of the Weibull statistics: To deduce the degree of convergence of the Weibull results to the actual measured wind speed values (v_{actua}) led to employing statistical analyses based on the coefficient of determination, R^2, the Root Mean Square Error (RMSE) and the Nash-Sutcliffe model Coefficient of Efficiency (COE) (Ajayi *et al*., 2011a). These are given by:

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

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

$$COE = 1 - \frac{\sum_{i=1}^{N}(y_i - x_i)^2}{\sum_{i=1}^{N}(y_i - \bar{x})^2} \quad (7)$$

Wind energy per unit area: The average wind energy extractable from the wind by a wind turbine is obtained from the average power by:

$$E = P\times\eta\times T_i \quad (8)$$

Where:

η = Turbine efficiency

T_i = Mean period

Moreover, the mean period, T_i, is given by the Rayleigh probability distribution model as:

$$T_i = T_{max} e^{-\frac{\pi}{4}\left(\frac{v_m - 1}{v_m}\right)^2} \quad (9)$$

where, T_{max} is maximum time period for a year in hours = 8760 h.

Substituting Eq. 9 into 8 gives:

$$E_{ave} = 10529.52\times C_p\times\eta\times n\left(v_m^3\times e^{-\frac{\pi}{4}\left(\frac{v_m - 1}{v_m}\right)^2}\right) \quad (10)$$

where, E_{ave} is Average wind energy flux density.

Equation 10 is therefore, the general expression for annual wind energy flux density in Wh/m^2 year.

From Eq. 10, it is clear that:

$$E_{ave} = f(v_m) \quad (11)$$

Thus a regression of E against v_m for different values of v_m for a particular location gives the wind energy per unit area for the location. Furthermore, the outcome of the regression analysis can also give the constitutive relationship between wind energy and mean speed.

Modelling wind energy potential of the sites and zone: From Eq. 10, it is noted that the values of E will be determined, apart from those of the mean wind speeds, by the values of η and C_p. Thus assuming C_p = 1 and varying η within the range $0.15\leq\eta\leq 1$ for Ikeja station for instance gives Table 2.

A regression analysis of E against v_m of Table 2 gives Fig. 11 for the different values of η. Figure 11 reveal that, as the values of η increase, the values of the harvested wind energy increased. Also observed from Fig. 11 is the changing value of the coefficient of v with those of η. Thus it can be deduced from Fig. 11 that:

Table 2: The values of wind energy per unit area corresponding to various values of turbine efficiency for Ikeja station

Year	Annual average wind speed ($m\ sec^{-1}$)	$\eta = 0.15$	$\eta = 0.3$	$\eta = 0.45$	$\eta = 0.6$	$\eta = 1.0$
1987	3.03	30747.04	61494.08	92241.12	122988.16	204980.27
1988	4.21	74568.37	149136.74	223705.12	298273.49	497122.48
1989	4.28	78234.76	156469.53	234704.29	312939.05	521565.08
1990	3.42	42524.29	85048.57	127572.86	170097.15	283495.25
1991	2.93	28126.98	56253.96	84380.94	112507.92	187513.20
1992	3.48	44495.33	88990.65	133485.98	177981.30	296635.50
1993	4.04	66829.76	133659.52	200489.28	267319.04	445531.74
1994	4.83	108807.70	217615.39	326423.09	435230.78	725384.64
1995	4.97	117246.09	234492.19	351738.28	468984.38	781640.63
1996	4.71	101270.50	202540.99	303811.49	405081.99	675136.65
1997	4.33	80743.79	161487.58	242231.37	322975.16	538291.94
1998	4.58	94086.41	188172.82	282259.23	376345.64	627242.73
1999	5.33	142656.45	285312.91	427969.36	570625.82	951043.03
2000	6.29	225674.30	451348.60	677022.89	902697.19	1504495.32
2001	6.93	295141.94	590283.88	885425.82	1180567.76	1967612.93
2002	6.69	268105.17	536210.35	804315.52	1072420.70	1787367.83
2003	4.78	105245.86	210491.71	315737.57	420983.43	701639.04
2004	4.38	83305.26	166610.53	249915.79	333221.05	555368.42
2005	4.81	107271.60	214543.20	321814.81	429086.41	715144.01
2006	4.93	115097.37	230194.74	345292.11	460389.47	767315.79
2007	5.21	133622.39	267244.77	400867.16	534489.54	890815.90

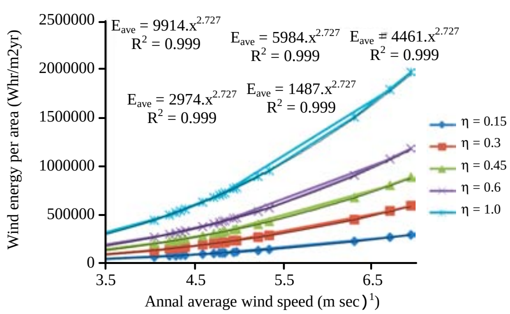

Fig. 11: Regression plots of variation of wind energy against monthly wind speed for Lagos Island

$$E_{ave} = \alpha v^{2.727} \quad (12)$$

$$\alpha = f(n) \quad (13)$$

In order to establish the exact relationship of Eq. 12 and 13 led to Fig. 12. Figure 12 therefore, demonstrates that Eq. 12 can be re-written as:

$$E = 9913 \times \eta \times v^{2.727} \quad (14)$$

Moreover, varying the values of C_P, as was done for η and the number of stations (n) from 1 to as many gave Eq. 15 as:

$$E_{ave} = 9913 \times \eta \times C_p \times n \times v^{2.727} \quad (15)$$

Equation 15 is therefore, the constitutive wind energy model which is suitable for analyzing wind energy

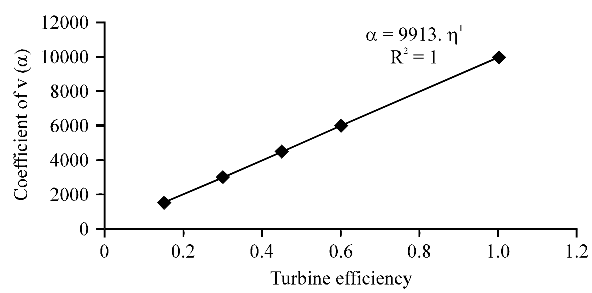

Fig. 12: Regression of variation of coefficient of speed with the turbine efficiency

situation of Ikeja station. Repeating the procedure for the other stations gave Eq. 16 to 25:

- Lagos island:

$$E_{ave} = 9502 \times \eta \times C_p \times n \times v^{2.727} \quad (16)$$

- Lagos (Marine):

$$E_{ave} = 10542 \times \eta \times C_p \times n \times v^{2.680} \quad (17)$$

- Ijebu Ode:

$$E_{ave} = 10745 \times \eta \times C_p \times n \times v^{2.667} \quad (18)$$

- Abeokuta:

$$E_{ave} = 11192 \times \eta \times C_p \times n \times v^{2.627} \quad (19)$$

- Ondo:

$$E_{ave} = 10409 \times \eta \times C_p \times n \times v^{2.726} \quad (20)$$

- Akure:

$$E_{ave} = 10727\times\eta\times C_p\times n\times v^{2.665} \quad (21)$$

- Oshogbo:

$$E_{ave} = 10936\times\eta\times C_p\times n\times v^{2.650} \quad (22)$$

- Shaki:

$$E_{ave} = 10141\times\eta\times C_p\times n\times v^{2.711} \quad (23)$$

- Iseyin:

$$E_{ave} = 10777\times\eta\times C_p\times n\times v^{2.668} \quad (24)$$

- Ibadan:

$$E_{ave} = 10513\times\eta\times C_p\times n\times v^{2.684} \quad (25)$$

The R^2 values that relates to the models all lie within $0.998\leq R^2\leq 1.000$.

To determine the magnitude of E for the entire zone, the arithmetic mean of the annual wind speeds of all stations within the zone was employed. This gave:

$$E_{ave} = 10480\times\eta\times C_p\times n\times v^{2.684} \quad (26)$$

RESULTS AND DISCUSSION

Wind profile characteristics of the stations/sites: Figure 2 and 3 presents the 21 years' monthly and annual average wind speed distributions across the stations/sites in the zone. While Fig. 2 and 3 reveal fluctuations in magnitude of the wind profiles across the stations, Fig. 2 shows fairly stable distributions with Abeokuta the most stable of the profiles. Observation of Fig. 2 and 4 to 8 reveal that the period of highest potential for wind energy harvest lie within February to July and that for lowest yield is within September to November across the zone with only few exceptions.

Ranking the sites/stations according to the monthly variations of the magnitudes of their average wind speed profiles (Fig. 9) gave Lagos Island as the best site followed closely by Ikeja, Shaki, Iseyin, Ibadan and Marina in order. The stations in Abeokuta and Ondo experienced the least magnitudes of wind profiles across the period. Figure 10 presents the ranking according to the range of annual average wind speeds. This also shows Lagos Island as the best, followed by Ikeja. Abeokuta and Ondo are the least. Based on state by state analysis, the state with more than one stations are shown in Fig. 4 to 7. Ranking the sites in each state in terms of good wind energy potential presents Lagos Island and Ikeja in Lagos state, Akure in Ondo state, Ijebu Ode in Ogun state and, Shaki and Iseyin in Oyo state.

Average range of wind energy potential at a local site: Equations 15 to 25 gives the magnitude of wind energy per unit area that can be generated from each of the sites studied. The obtained values of R^2 reveal that the models of Eq. 15 to 25 are adequate to explain the changes in the magnitudes of wind energy per unit area of the different stations. Based on this, there is however a need to develop a model which will be suitable to determine the range of wind energy potential of any site from any location within the zone. With such model, it will be very easy to estimate the range of average wind energy that can be harvested based on the value of wind speed from any site within the zone. Thus, to develop this model, the statistical tolerance limit method was employed with Eq. 15 to 25. The result is given as:

$$8474.97\eta\times C_p\times v^{2.518}\leq E_{ave}\leq 12621.80\eta\times C_p\times v^{2.848} \quad (27)$$

Going by Eq. 27, the magnitude of average wind energy per unit area that could be generated from any station in the analysis range between $8474.97\eta\times C_p\times v^{2.518}$ and $12621.80\eta\times C_p\times v^{2.848}$.

For instance, in each of the stations with the average annual wind speeds, the magnitude of wind energy that can be produced from an ideal wind turbine (with the assumption that ($\zeta = C_p\times\eta = 1$)) is given in Table 3.

Table 3 clearly demonstrates that the results from Eq. 15 to 25 fall within the range of Eq. 27. This means that, Eq. 27 is a better model representation for the whole of the zone. Thus the knowledge of the average wind speed of any site within the zone can lead to determining the range of average energy flux density harvestable from the location. However, since investors are always interested in the optimum value of wind harvest, the optimum value of the wind energy that can be harvested from a site, based on the magnitude of the mean wind speed is given as:

$$E = 12621.80_{\eta}\times C_p\times n\times v^{2.8} \quad (28)$$

Equation 28 is therefore, a useful model for estimating the maximum likelihood of wind energy flux density harvestable from any site within the zone.

Performance evaluation of the model represented by Eq. 28: Since the Eq. 27 is found to be suitable for all sites within the studied zone, it became necessary to carry out

Table 3: Magnitude of wind energy that can be produced from a wind turbine based on Eq. 15 to 25 and 27

Station	Average speed (m sec^{-1})	Eq. 12 to 21	Minimum from Eq. 27	Maximum from Eq. 27 (i.e., E_{op})
Ikeja	4.67	664351.54	411499.93	1019399.29
Lagos island	5.03	808840.63	494397.11	1254574.57
Lagos marine	3.72	355310.83	230928.98	530361.61
Ijebu Ode	3.39	278441.32	183102.58	407924.44
Abeokuta	2.50	124042.78	85007.37	171265.10
Ondo	1.97	66473.58	46982.55	87578.85
Akure	3.26	249527.18	165727.52	364422.49
Oshogbo	3.16	230751.69	153624.36	334467.83
Shaki	4.35	544171.25	342496.68	828292.95
Iseyin	3.92	412307.17	264166.35	617482.58
Ibadan	3.91	407862.48	262217.68	612333.15

Table 4: Weibull results and the percentage difference between the Weibull results and the optimum value-result of Eq. 22

Station	v_{actual} (m sec^{-1})	σ_{actual} (m sec^{-1})	k	c (m sec^{-1})	$\sigma_{weibull}$ (m sec^{-1})	$v_{weibull}$ (m sec^{-1})	$E_{weibull}$ (Wh/m^2 year)	R^2	RMSE	COE	E_{op} (Wh/m^2 year)	Fractional difference
Ikeja	4.67	1.42	4.02	5.15	1.30	4.67	1275430.49	0.96	0.27	0.96	1019399.29	0.20
Lag. island	5.03	1.28	3.68	5.63	1.54	5.08	1739748.23	0.89	0.32	0.94	1254574.57	0.28
Lag. marine	3.72	0.96	4.78	4.05	0.89	3.71	581622.29	0.94	0.22	0.94	530361.61	0.09
Abeokuta	2.50	0.70	4.65	2.75	0.62	2.51	167195.06	0.94	0.19	0.92	171265.10	-0.02
Ijebu Ode	3.39	1.03	3.97	3.74	0.96	3.38	490698.63	0.96	0.18	0.97	407924.44	0.17
Akure	3.26	0.84	4.95	3.55	0.75	3.26	385142.15	0.89	0.37	0.81	364422.49	0.05
Ondo	1.97	1.08	2.07	2.21	1.00	1.96	142528.58	0.99	0.15	0.98	87578.85	0.39
Oshogbo	3.16	1.01	3.46	3.52	1.01	3.16	434987.81	0.99	0.09	0.99	334467.83	0.23
Ibadan	3.91	1.08	3.71	4.36	1.18	3.93	803195.79	0.93	0.20	0.97	828292.95	-0.03
Iseyin	3.92	1.38	3.15	4.38	1.36	3.92	879208.83	0.99	0.14	0.99	617482.58	0.30
Shaki	4.35	1.43	3.51	4.83	1.37	4.34	1117857.99	0.96	0.22	0.98	612333.15	0.45

Table 5: Comparing results from using Eq. 22 with those of other published reports

Study	v_{actual} (m sec^{-1})	k	c (m sec^{-1})	$E_{weibull}$ (Wh/m^2 year)	E_{op} (Wh/m^2 year)	Fractional difference
Keyani *et al.* (2010)	4.24	2.02	4.81	721420.00	773987.75	-0.07
Kamau *et al.* (2010)	11.15	2.82	12.51	9609720.00	12127188.18	-0.21
Akpina and Akpinar (2005a)	2.26	1.52	2.52	136682.30	128388.78	0.06

an accuracy check on the model. This is to determine its level of accuracy. In order to do this, the 2-parameter Weibull statistical distribution was fitted to the annual average wind speed distribution of the stations. The results from the Weibull analysis were then compared with those obtained for the optimum value of Eq. 28. Table 4 presents the outcome of these analyses. Table 4 shows that the values of the E_{op} are able to predict between 54 and approximately 100% of the values of $E_{Weibull}$. In addition, the results of E_{op} reveal that it is possible to generate more than 1 MWh/m^2 year of wind electricity from Ikeja and Lagos Island. It also shows the possibility of wind electricity production of other sites. Furthermore, it reveals that Abeokuta and Ondo stations are not very adequate for large scale wind power project due to the low values. Thus, with the knowledge of a single wind speed from a site, it is possible to have an instant evaluation of the probability of the site's suitability.

Further from Table 4, it shows that the values of the Weibull 2-parameters fall within the range $2.07 \leq k \leq 4.95$ and $2.21 \leq c \leq 5.63$, respectively. The high values of k and c ($k \geq 2.0$ and $c \geq 2.0$) indicates that the data spread exhibited good uniformity with relatively small scatter and that the Weibull mean wind speed results were very close to the actual value (Ajayi *et al.*, 2011b). Further to this, the Weibull estimation results of R^2, RMSE and COE show that the Weibull distribution is adequate at explaining the situation of wind profiles at the sites. Thus comparing the Weibull results with those from Eq. 28 is worthwhile. It is also worth noting that the model of Eq. 28 can be internationalized for preliminary site study provided the wind distribution of the location is similar to those of this study.

When the model was tested with other published reports (Akpinar and Akpinar, 2005a; Kamau *et al.*, 2010; Keyhani *et al.*, 2010), it gave Table 5. Akpinar and Akpinar (2005a) carried out the statistical analysis of the wind speed data of Keban-Elazig, Turkey. Kamau *et al.* (2010) on the other hand studied the 6 years wind data for Marsabit Kenya, while Keyhani *et al.* (2010) carried out the assessment of wind energy potential for power generation of Tehran, Iran. The studies employed the 2-parameter Weibull statistical distribution for the analyses. Table 5 therefore showed that the model represented by Eq. 28 can be used as a preliminary check to predict the likely potential of wind energy harvestable from a site before embarking on detailed assessment study of such site.

Application of wind turbine parameters: The analyses carried out above were done on the basis of an ideal turbine (i.e., assuming 100% efficiency). However, an actual turbine cannot extract more than 59.3% (according to Betz law) of the power in an undisturbed tube of air of the same area. In practice, the fraction of power extracted will always be less because of mechanical imperfections. These mechanical imperfections and also factors due to shape and size of rotors as well as the fluctuations of the wind speeds will lead to a further decline in the efficiency of a practical wind turbine. Thus to determine the likely magnitude of wind power harvestable from a practical wind turbine will require inputting the turbine parameters of C_p and η into Eq. 28.

CONCLUSION

The study has been used to develop a theoretical model for preliminary study of the wind speed potential for energy production. It made use of 21 years (1987-2007) monthly mean speeds for 11 stations from the south-west geopolitical zone of Nigeria. The outcome of analyses led to the development of a model which can be used for preliminary evaluation of the likelihood of a site's capacity for wind energy generation. The optimum wind energy model developed is given as: $E_{op} = 12621.80 \times \eta \times C_p \times v^{2.848}$. It is thought that, although the model was developed using data from Nigeria, it could be employed for such preliminary analysis of any site around the world, especially those with wind profile distributions similar to those of this study. The purpose of the model was to serve as a tool for preliminary prediction of the likelihood of developing a site for wind farm purposes. The basic input of the model is the wind speed of the site. Based on the result from the model, a decision can be taken on the possibility of carrying out a detail site assessment study. This will involve measuring the site's wind speed over a period of time and years, before determining the site's potential by Weibull or any other statistical means.

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