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Electricity Generation Potential and Energy Cost of Wind Conversion Systems in Ikeja Southwest Nigeria

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ABSTRACT

In this study, the wind electricity generation potential and energy cost at Ikeja were investigated using 31 years wind speed data obtained from Nigeria Meteorological Agency. The study addresses the challenges of inadequate electricity supply and the development of alternative source of electricity. The measured data, captured at 10m height were subjected to 2-parameter Weibull and other statistical analysis. Weibull analysis of wind speed showed good fit between actual data and Weibull predicted data confirming the adequacy of the model. The value of wind speed at 10m height ranged between 3.47m/s and 5.33m/s with annual average of 4.5m/s. Also, the Wind Power Density (WPD) ranged between 116.3 W/m^2 and 423.3W/m^2 with annual average value of 257.85W/m^2. The mean electric power outputs from the model turbines varied between 11KW and 290KW while its Capacity Factor (CF) ranged between 13.8% and 0.36%. Also, the generation cost per kilowatt-hour varied between \$0.11 and \$2.39 annually. Therefore, the wind energy potential at Ikeja could be adjudged marginal and belonging to wind power class 2. The generation cost of wind electricity is cost-effective in the months of April and August while cost-deficit in the remaining months of the year. The location is considered suitable for small to medium

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scale wind power generation, but economically infeasible for large scale grid connected wind electricity generation.

Keywords: Capacity factor, energy cost, mean power output

INTRODUCTION

Energy availability has been identified to be one of the factors that have major effect on the socio-economic life of any society (Herman, 2001). The poor state of electrical power supply in Nigeria has been widely viewed as one of the major constraint to the nation economic growth (Nkalo & Agwu, 2019). The electrical energy in particular is an important component for the development of any economy. Besides capital and labor, electricity is the third important factor of production in economic model (Ezema et al., 2016). Lack of electricity or its inadequacy had been said to be a source of social and economic poverty (Nkalo & Agwu, 2019). Nigeria, despite abundance natural resources, including fossil fuel and renewable energy resources, has one of the lowest net electricity generation (Adebayo, 2014). The report has it that about 75millions Nigerian lack access to adequate electricity (Adebayo, 2014). Lagos state which is Nigeria economic center is not an exception in the terms of inadequate electricity supply from the national grid.

The present electricity demand of Lagos state alone is in needs of additional 4000MW (Oladipo et al., 2018). While the entire country installed electricity generation capacity is 12,522MW and available capacity of 6,056MW (NERC, 2019). The actual electricity generated and distributed in Nigeria is often less than 4000MW and sometimes drops as low as below 1000MW (Oladipo et al., 2018). This shows that the Lagos state could not attain self-sufficiency in her energy need by depending solely on the supplies from the national grid. The inadequate electricity supply from national grid has made most of the residents and industries to resort to power generation from small, medium and heavy-duty generating sets (Odunola et al., 2018).These have become major source of environmental pollution and health hazard. The environmental pollution from fossil fuel combustion has been described as the world most significant threat to children's health and future and is significant contributors to global inequality and environmental injustice (Federica, 2018). Considering the high energy demand of Lagos, no single energy resources can sustainably meet its demand without energy mix; therefore, integrating all exploitable energy sources is a viable way of achieving stability in energy supply of Lagos state (Uzoma et al., 2014).. The economic growth of Lagos city has been influenced by the high population density, the commercial and industrial activities within the metropolis. Since energy growth, economic development and sustainable development are grossly inseparable (Uzoma et al, 2014).

Therefore, there is a need for the development of alternative and sustainable energy source that will be commensurate to the population growth and economic development of the state.

It has been widely accepted that wind energy is becoming the fastest growing renewable sources of energy in both developed and developing countries (Ajayi et al., 2014). In Sub-Sahara Africa, particularly the West Africa region, no country has yet generated grid electricity from wind despite the identified opportunities (Ajayi, 2013). The challenge of wind energy project development in Sub-Sahara Africa may however be linked to inadequate measurement, lack of assessment studies and/or improper classification of the location wind regime (Okeniyi et al., 2015).

Some of the previous research study that have assessed wind energy potential in different locations in Nigeria include the work of Ajayi, (2010), Agbetuyi et al. (2012), Adaramola et al. (2011) and Fagbenle et al. (2011). Majority of the studies have focused on the northern part of the country. This may probably be due to fact that wind speeds are generally believed to be weak in the southern part. But coastal regions and offshore areas of southwest and south-south have been reported to have potentialities for strong wind (Oyewole & Aro, 2018; Ajayi, 2010). Also, due to varying roughness of the country, large differences may exist within the same locality in term of wind energy potential (ECN-UNDP, 2015). Therefore, more needs to be done to expose the wind profile of the southern regions of Nigeria (Ajayi, et al., 2014). Some of the previous studies aimed at assessing the wind energy potential and energy cost of locations within the southwest geopolitical zone includes the work of Ajayi et al. (2014). They presented study on the wind energy potential and the cost-benefit analysis of wind power generation in ten selected sites within the southwest geopolitical zones of Nigeria. There result showed that locations in Lagos and Oyo state were suitable for large scale wind electricity generation while energy cost analysis showed that generation cost varied between €0.02 and €5.03 depending on the turbine model employed. Likewise, Nze-Esiaga and Okogbue (2014) studied the wind power generation potential as a power generation sources in five locations of south western Nigeria. There result showed that Ikeja had better wind speed profile in the wet season compared to the other locations considered. They concluded that the wind speed of most of the locations was viable for wind electricity.

In this study, Weibull model was employed in the wind speed analysis. The 2-parameter Weibull distribution function out of all probability density functions has enjoyed wide use (Fadare, 2008; Carta, et al., 2009). This is because the 2-parameter Weibull model produces better fit to the observed data and could be use to determine the two important wind speeds (maximum energy carrying wind speed and most probable wind speed) for wind farm evaluation and further technical analyses (Akpinar & Akpinar, 2005). Also, the quantitative assessment of wind electricity generated was carried out using power-output simulation of four different commercial wind turbines while energy cost was based on present value cost (PVC) method. The result will lead to increase in the reliability and predictability of wind as alternative source of energy. It will also show how wind electricity potential and energy cost vary across months and seasons of the year. This will enable the electricity grid to make informed decision on the management and accommodation of variable nature of wind energy. It will also be useful to individuals, government at all levels, wind energy assessors and policy makers regarding wind electricity generation and investment.

MATERIAL AND METHOD

Thirty-one years (1980-2010) monthly mean wind speed data measured at Ikeja airport was obtained from the Nigeria Meteorological Agency (NIMET), Oshodi, Lagos State, Nigeria. The data was recorded continuously using cup-generator anemometer at a height of 10m. The high variability in wind speed data necessitated the use of probability distribution function in the data analysis. Though there are many probability distribution functions that describe wind speed distribution in a particular location. However, Weibull distribution has been found to be most accurate and adequate in analyzing and interpreting wind speed data (Carta et al., 2009). In this study, two-parameter Weibull distribution model was used in the analysis of wind speed data. The estimated Weibull scale (c) and shape parameters (k) were used in the calculation of other wind parameters while the cost of wind electricity was estimated using the present value cost method (PVC).

Weibull Parameters Estimation

The shape parameters (k) and scale parameter (c) were estimated based on the maximum likelihood method (MLM). The MLM technique estimates the Weibull shape parameter (k) and the scale parameter (c) using the following Equation 1 and 2

$$k = \left\{ \frac{\sum_{i=1}^{n} v_i^k \ln v_i}{\sum_{i}^{n} v_i^k} - \frac{\sum_{i=1}^{n} \ln v_i}{n} \right\}^{-1} \qquad [1]$$

$$\mathbf{c} = \left\{ \frac{1}{\mathbf{n}} \sum_{\mathbf{i}}^{\mathbf{n}} = \mathbf{v}_{\mathbf{i}}^{\mathbf{k}} \right\}^{1/\mathbf{k}} \qquad [2]$$

where vi is the wind speed in time step i and n is the number of non-zero wind speed data points.

The mean wind speed (Vd) can be evaluated from the actual data using the Equation 3

$$v_d = \frac{1}{n} \left(\sum_{i=1}^{n} v_i \right) \qquad [3]$$

while the predicted weibull mean wind speed (Vw) is defined in terms of the Weibull parameters k and c is given according to Equation 4

$$v_{weibull}\left(= c\Gamma 1 + \frac{1}{k}\right) \qquad [4]$$

Performance Evaluation of Weibull Distribution Model

The performance of Weibull model used in the prediction of monthly mean wind speeds was evaluated using the following statistical test; correlation coefficient (R2), Chi-square (χ2), root mean square error (RMSE) and coefficient of efficiency (COE). These test models are estimated using the following Equation 5, 6, 7 and 8

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

$$\chi^2 = \frac{\sum_{i=1}^{n}(y_i - z_i)^2}{N - n} \qquad [6]$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2\right]^{\frac{1}{2}} \qquad [7]$$

$$COE = \frac{\sum_{i=1}^{N}(y_i - x_i)^2}{\sum_{i=1}^{N}(y_i - z_i)^2} \qquad [8]$$

Wind Power Density

The wind power density (WPD) is the amount of wind energy transported across a unit area in unit time. This important parameter can be estimated from the values of Weibull scale and shape parameters using the expression given in Equation 9

$$WPD = \frac{1}{2}\rho c^3\left(1 + \frac{3}{k}\right) \qquad [9]$$

where ρ is the location's air density(kg/m^3).

Wind resources are usually represented by wind power classes. Table 1 shows the international wind power classification at 50m hub height. Each class represents a range of wind power densities and equivalent mean wind speed.

Table 1

International wind power classification at 50m hub height (Ahmed, 2016)

Wind power class	WPD (W/m^2)	Wind speed (m/s)	Remark
1	≤200	≤5.6	Poor
2	≤300	≤6.4	Marginal
3	≤400	≤7.0	Fair
4	≤500	≤7.5	Good

Table 1 *(Continued)*

Wind power class	WPD (W/m^2)	Wind speed (m/s)	Remark
5	≤600	≤8.0	Excellent
6	≤800	≤8.8	Outstanding
7	≤2000	≤11.9	Superb

Wind Turbulence Intensity

Wind turbulence is the rapid disturbances or irregularities in the wind speed, wind direction and wind vertical component.. The most common indicator of turbulence for sitting purpose is the standard deviation from the mean wind speed. Turbulence intensity can be estimated by normalizing standard deviation with the mean wind speed using the expression given in Equation 10

$$\mathrm{TI} = \frac{\sigma}{\bar{v}} \qquad [10]$$

Turbulence intensity, a dimensionless quantity is a relative indicator of turbulence level. Low level is indicated by values less than or equal to 0.10 (≤ 0.10), moderate turbulence level is indicated by values greater than 0.10 and up to 0.25 (0.10 ≤ TI ≤ 0.25) while high turbulence level is indicated by values greater than 0.25 (TI > 0.25) (Ahmed, 2016).

Power Law Exponent

The mean horizontal wind speed is zero at the earth's surface and increases with altitude in the atmospheric boundary layer. Wind data sets are usually collected at 10m hub height, thereby necessitating extrapolation of wind speed data for higher hub heights using the power index law. The wind speed extrapolation according to power law is given in Equation 11

$$v = v_o \left(\frac{H}{H_o}\right)^{\alpha} \qquad [11]$$

where v is the wind speed at the turbine hub height H, vo is the wind speed at original height Ho and α is the surface roughness coefficient or empirical wind shear exponent. The values of α is taken as 1/7 for most sites with uniform terrain (Ahmed, 2016). Since wind speed varies with height, Weibull parameters c and k must be corrected for different hub heights. This can be determined using Frost Equation 12 and 13

$$k = k_r \left[\frac{1 - 0.088\ln\left(\frac{H_o}{10}\right)}{1 - 0.088\ln\left(\frac{H}{10}\right)}\right] \qquad [12]$$

$$c = c_r \left(\frac{H}{H_o} \right)^{\alpha} \qquad [13]$$

where krand cr represent the shape and scale parameters at higher hub heights

Maximum Energy Carrying Speed and Most Probable Wind Speed

The other parameters of utmost interest to wind resource assessors are the maximum energy carrying speed (vEmax) which is the wind speed carrying maximum wind energy and the most probable wind speed (vmp) which is the modal wind speed for the given wind distribution. These parameters can be estimated from the shape parameter k and scale parameter c using the given Equation 14 and 15

$$v_{Emax} = c \left(\frac{k+2}{k} \right)^{\frac{1}{k}} \qquad [14]$$

$$v_{mp} = c \left(\frac{k-1}{k} \right)^{\frac{1}{k}} \qquad [15]$$

Mean Power Output

The performance of the wind turbine can be examined by the mean power output. The mean electrical power output of a model wind turbine requires simulation of the equation given according to the Equation 16

$$P_e = \begin{cases} P_R \dfrac{v^k - v_c^k}{v_R^k - v_c^k} & v_c \leq v \leq v_R \\ P_R & v_R \leq v \leq v_F \\ 0 & v > v_F and v < v_C \end{cases} \qquad [16]$$

where PR is the rated electrical power, vC is the cut-in wind speed, vR is the rated wind speed, vF is the cut-out speed and k is the shape parameter of the model wind turbine. Table 2 shows the technical specification of the model wind turbines used for this study which was retrieved from (http://en.windturbinesmodel.com/).

Table 2

Technical specifications and wind speed parameter of model wind turbines (http://en.windturbinesmodel.com/)

TECHNICAL PARAMETERS	WIND TURBINE MODELS			
	VENSYS 87	VESTAS V90	GAMESA G97	SUZZLON S88
Rated speed	12m/s	14m/s	12m/s	11.2m/s
Cut-in speed	3m/s	4m/s	3.5m/s	3.5m/s
Cut-out speed	22m/s	25m/s	25m/s	25m/s
Rotor swept area	5890m^2	6362m^2	7390m^2	6082m^2
Rotor diameter	87m	90m	90m	88m
Speed range	9-17.3rpm	9.9-18.4rpm	10-18rpm	7.8-15rpm
Rated power	1500KW	3000KW	2000KW	2100KW
Hub height	85m	80m	78m	80m

Capacity Factor

The capacity factor represents the fraction of the mean power output to the rated electrical power of the turbine. It can be used to predict wind turbine energy production and its economic feasibility. The capacity factor can be estimated from the Equation 17

$$C_f = \frac{P_e}{P_R} \qquad [17]$$

wherePe and PR are the mean power output and the rated electrical power of the wind turbine respectively.

Annual Energy Production

The annual energy production for a particular site is the total energy output of the wind turbine considering the power output at any wind speed and frequency of occurrence of that wind in a year. The accumulated annual energy output of a wind turbine can be estimated from the given Equation 18

$$E_c = P_e \times 8760(\mathrm{KWh}) \qquad [18]$$

wherePe is as defined above and the constant (8760) represents the total number of hours in the year.

Energy Cost

There are two notable methods used for estimating the generation cost of unit energy (1kilowatt-hour). They are the levelized cost of electricity (LCOE) method and the present value cost (PVC) method. Considering the instability of the Nigeria economy, the present value cost method was most suitable for this study. The cost of a kilowatt-hour of wind-generated electricity was estimated using the given Equation 19

$$C = \frac{C_I}{8760n}\left(\frac{1}{P_R C_F}\right)\left[1 + m\left\{\frac{(1+I)^n - 1}{I(1+I)^n}\right\}\right] \quad [19]$$

where CI= initial investment on the project, PR = rated power of the turbine, CF = capacity factor, m = annual operation and maintenance cost, I = interest rate and n = project life span.

The economic analysis of the model wind turbines was carried out based on the following assumptions;

(i) The useful life span of the wind turbine is assumed to be 20years
(ii) The interest rate and inflation rates were 20% and 16% respectively
(iii) Operating and maintenance cost was assumed to be 3.5% of the initial investment
(iv) Turbines cost is assumed to be $Million per Mega-Watt.

RESULT AND DISCUSSION

The thirty-one year's monthly mean wind speed data (1980-2010) obtained from NIMET was analyzed to obtain the mean wind speeds across months and seasons. Matlab computer programme was used for the estimation of the weibull shape (k) and scale (c) parameters based on the maximum likelihood technique (MLT). The result shown in Tables 3 was obtained from Weibull model while result shown in Table 4 was obtained from power simulation of the model wind turbine and cost analysis using the present value cost (PVC) method.

Wind Speed Characteristic at Ikeja

The variation of monthly mean wind speed for thirty-one years at different hub heights is shown in Figure 1. It could be observed from the plot that the value of mean wind speed varied with months and seasons of the year. It also showed that the magnitude of wind speed increased with elevation (hub heights). At the hub height of 10m, the monthly mean wind speed ranged between the minimum value of 3.47m/s and a maximum of 5.33m/s with annual average value of 4.5m/s.. The wind speed had a seasonal average value of 4.09m/s in dry season and 4.65m/s during the rainy season. It was observed that the monthly mean speed exceeded 5m/s in the months of March, April, July and August while it ranged between 4m/s and 4.9m/s in January, February, May, June and September.

Table 3

Results of Weibull based parameters estimated at 10m hub height

Period	V_{data}(m/)	$V_{weibull}$	C(m/s)	K	WPD(W/m^2)	TI	Vemax(m/s)	Vmp(m/s)
January	4.13	4.14	4.56	4.07	100.473	0.285714	5.030568	4.254783
February	4.53	4.52	5	3.8	136.4474	0.275938	5.588529	4.613904
March	5.07	5.06	5.61	3.65	196.2218	0.285996	6.323401	5.138872
April	5.08	5.07	5.57	4.39	177.4497	0.244094	6.06727	5.251488
May	4.32	4.32	4.75	4.26	111.4135	0.263889	5.199172	4.460859
June	4.41	4.42	4.89	3.76	128.2376	0.301587	5.477387	4.50398
July	5.07	5.07	5.59	4.06	185.2866	0.274162	6.169583	5.21392
August	5.33	5.31	5.89	3.67	226.5351	0.283302	6.631188	5.40096
September	4.51	4.51	5	3.67	138.5797	0.299335	5.629192	4.584855
October	3.83	3.82	4.21	4.08	78.98584	0.261097	4.642412	3.929645
November	3.47	3.47	3.84	3.75	62.17217	0.288184	4.303624	3.535181
December	3.73	3.73	4.14	3.66	78.76332	0.308311	4.663708	3.7943
Whole Year	4.46	4.5	4.95	3.45	138.3203	0.307175	5.651502	4.48247
Dry Season	4.09	4.18	4.66	3.32	117.5078	0.332518	5.371118	4.183149
Rainy Season	4.65	4.64	5.15	3.62	152.3705	0.286022	5.81537	4.709998
1980	5.5	5.53	5.95	6.18	190.8688	0.223636	6.226156	5.78246
1981	4.75	4.74	5.12	5.77	124.441	0.189474	5.391002	4.95387
1982	5.03	5.04	5.37	7.41	132.7044	0.163022	5.545983	5.265961
1983	3.85	3.85	4.17	5.44	68.62487	0.207792	4.417039	4.017167
1984	3	3	3.35	3.13	44.91386	0.346667	3.922821	2.962358

Table 3 *(Continued)*

Period	V_{data}(m/)	$V_{weibull}$	C(m/s)	K	WPD(W/m^2)	TI	Vemax(m/s)	Vmp(m/s)
1985	3.17	3.19	3.53	3.73	48.4128	0.29653	3.960593	3.246648
1986	2.75	2.78	2.92	10.1	19.69828	0.163636	2.972703	2.890012
1987	3.03	3.01	3.08	24.45	20.00993	0.036304	3.089921	3.074744
1988	4.21	4.22	4.66	3.85	109.8291	0.301663	5.194927	4.309826
1989	4.28	4.29	4.67	5.04	99.10738	0.238318	4.990165	4.469506
1990	3.42	3.42	3.73	4.9	51.03726	0.24269	3.999873	3.560229
1991	2.93	2.94	3.22	4.34	34.44322	0.276451	3.51384	3.031431
1992	3.47	3.48	3.77	5.68	49.94882	0.216138	3.97564	3.643633
1993	4.04	4.06	4.35	6.7	72.69333	0.178218	4.522945	4.24631
1994	4.83	4.84	5.21	6.17	128.2116	0.190476	5.452562	5.062806
1995	4.97	4.98	5.24	9.82	114.5777	0.132797	5.339855	5.183003
1996	4.71	4.72	4.95	10.95	94.25524	0.123142	5.026419	4.906897
1997	4.33	4.33	4.7	5.19	99.94014	0.2194	5.00465	4.510117
1998	4.58	4.58	4.88	7.33	99.90464	0.155022	5.043293	4.78332
1999	5.33	5.32	5.78	5.28	184.7182	0.213884	6.142537	5.554654
2000	6.29	6.29	6.71	7.42	258.7982	0.163752	6.929328	6.58036
2001	6.93	6.91	7.39	7	351.6941	0.15873	7.660136	7.22904
2002	6.69	6.69	7.35	4.34	409.6361	0.284006	8.020723	6.919572
2003	4.23	4.24	4.5	8.32	75.62937	0.165485	4.618036	4.431271
2004	3.67	3.66	3.96	5.6	58.17358	0.19891	4.181945	3.823312

Table 3 *(Continued)*

Period	V_{data}(m/)	$V_{weibull}$	C(m/s)	K	WPD(W/m^2)	TI	Vemax(m/s)	Vmp(m/s)
2005	3.87	3.85	4.11	7.52	59.2452	0.147287	4.240933	4.032748
2006	4.13	4.13	4.4	7.48	72.80271	0.150121	4.541614	4.316386
2007	4.17	4.16	4.53	5	90.72864	0.22542	4.845335	4.332277
2008	5.75	5.74	6.08	8.38	186.1825	0.130435	6.237289	5.988498
2009	5	5	5.31	7.98	125.6646	0.148	5.460921	5.221651
2010	5.25	5.23	5.47	11.45	125.9953	0.085714	5.547453	5.426515

Table 4

Result of power output simulation of model turbines and energy cost per kilo-watt-hour90m hub heights

Period	V	C	K	Mean Power Output (KW)				Capacity Factor			
				VESTAS V90	GAMESA G97	SUZZLON S88	VENSYS 87	VESTAS V90	GAMESA G97	SUZZLON S88	VENSYS 87
January	5.65	6.24	5.04	25.59	40.99	61.01	32.33	0.008	0.020	0.029	0.021
February	6.20	6.84	4.71	56.73	83.50	121.49	64.86	0.018	0.041	0.057	0.043
March	6.94	7.68	4.52	115.51	161.05	231.39	123.4	0.038	0.080	0.110	0.082
April	6.96	7.62	5.44	63.423	100.46	153.64	76.34	0.021	0.050	0.073	0.050

Table 4 *(Continued)*

Period	V	C	K	Mean Power Output (KW)				Capacity Factor			
				VESTAS V90	GAMESA G97	SUZZLON S88	VENSYS 87	VESTAS V90	GAMESA G97	SUZZLON S88	VENSYS 87
May	5.91	6.50	5.28	27.71	44.773	67.72	34.80	0.009	0.022	0.032	0.023
June	6.04	6.69	4.66	50.93	75.234	109.09	58.80	0.016	0.037	0.051	0.039
July	6.94	7.65	5.08	82.51	123.41	183.54	94.10	0.027	0.061	0.087	0.062
August	7.30	8.06	4.54	145.25	201.50	289.99	153.63	0.048	0.100	0.138	0.102
September	6.17	6.84	4.54	62.56	90.303	129.96	70.38	0.020	0.045	0.061	0.046
October	5.24	5.76	5.05	15.61	26.49	39.47	21.45	0.005	0.013	0.018	0.014
November	4.75	5.25	4.64	10.89	20.49	29.69	17.84	0.003	0.010	0.014	0.011
December	5.10	5.66	4.53	20.77	34.12	49.06	28.36	0.006	0.017	0.023	0.018
Whole Year	6.10	6.77	4.27	72.50	101.45	143.35	79.64	0.024	0.050	0.068	0.053
Dry Season	5.59	6.38	4.11	52.07	74.75	104.48	60.33	0.017	0.037	0.049	0.040
Rainy Season	6.36	7.05	4.48	76.79	108.45	155.	84.43	0.025	0.054	0.074	0.056

Table 4 *(Continued)*

Period	Energy Cost ($ per Kilo-Watt-hour)			
	VESTAS V90	GAMESA G97	SUZZLON S88	VENSYS 87
January	1.018	0.423	0.298	0.402
February	0.459	0.208	0.150	0.200
March	0.225	0.107	0.078	0.105
April	0.410	0.172	0.118	0.170
May	0.940	0.387	0.269	0.374
June	0.511	0.230	0.167	0.221
July	0.315	0.140	0.099	0.138
August	0.179	0.086	0.062	0.084
September	0.416	0.192	0.140	0.185
October	1.669	0.655	0.462	0.607
November	2.390	0.847	0.614	0.729
December	1.254	0.509	0.371	0.459
Whole Year	0.359	0.171	0.127	0.163
Dry Season	0.500	0.232	0.174	0.215
Rainy Season	0.339	0.159	0.116	0.154

The monthly mean wind speed was less than 4m/s in October, November and December. This suggested that the potential of wind energy is fair in March, April, July and August, marginal in the months of February, May, June and September and poor in the months of January, October, November and December.

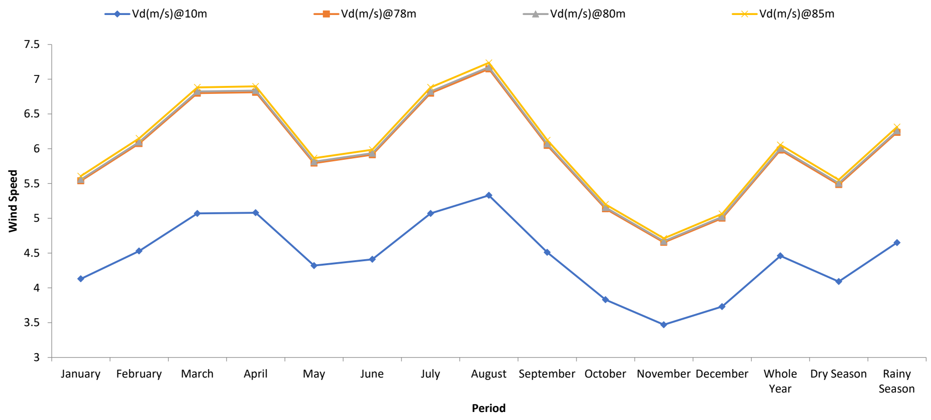

Figure1. Monthly and seasonal variation of average wind speed (1980–2010) at different heights

Wind Speed Frequency Distribution

Wind speed frequency distribution shows the cumulative time the wind blows at prescribed value or range of values. It is a relative indicator of energy input to a wind turbine. The frequency of occurrence of a particular wind speed range is critical information required in wind resource assessment. Figure 2 shows the wind speed frequency distribution of Ikeja based on the thirty-one year's monthly mean wind speed. The frequency distribution showed that there were three dominant wind speed ranges with a percentage frequency higher than 20%. These included ranges of 3-3.9m/s, 4-4.9m/s, and 5-5.9m/s. The wind speed range with the highest frequency of occurrence of 27% was between the range 3-3.9m/s. The plot also indicated that wind speed above 3m/s occurred with a cumulative frequency of over 70%. Since the cut-in speed of most modern wind turbine is between 3m/s to 3.5m/s, therefore, it can be inferred that most modern wind turbine will generate electricity regularly at Ikeja location.

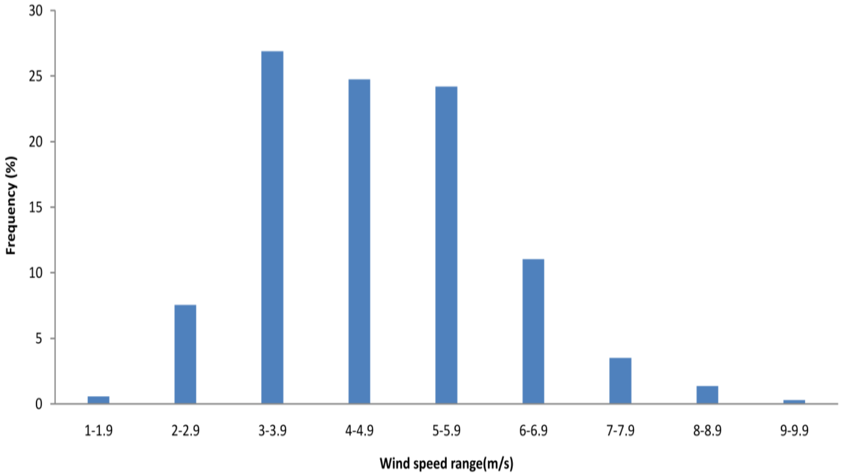

Figure 2. Wind speed frequency distribution for Ikeja (1980-2010)

Wind Turbulence Intensity

Figure 3 shows the plot of yearly variation of wind turbulence intensity. The plot reveals that the turbulence intensity varies with year. The turbulence intensity ranges between low values of 0.03 and a high value of 0.34 within the thirty-one years considered. High-level turbulence (TI > 0.25) was observed in the years 1985, 1986, 1989, 1992, 2002 and 2003 while low-level turbulence (<0.1) was observed in the year 1987. The turbulence intensity of the remaining years of 1980, 1981, 1982, 1983, 1984 , 1988, 1990, 1991, 1993, 1994,

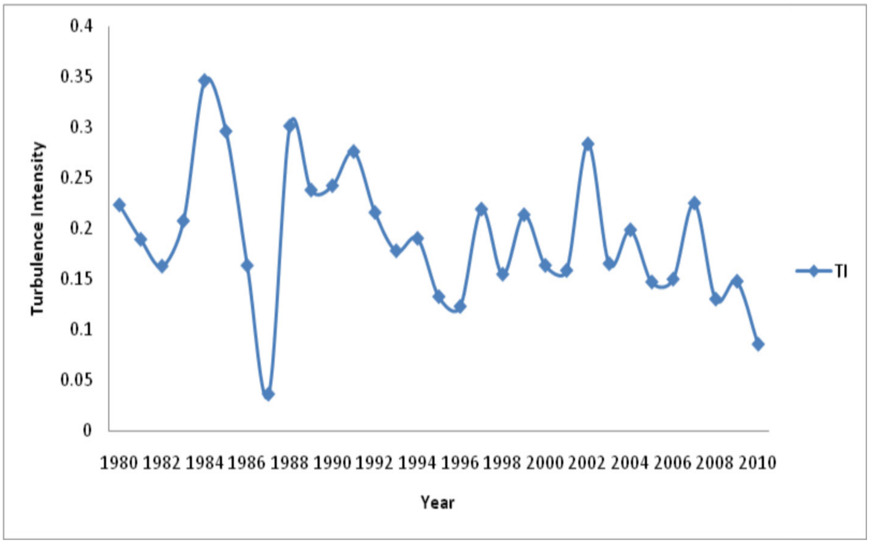

Figure 3. Yearly variation of wind turbulence intensity (1980 – 2010)

1995, 1996, 1997, 1998, 1999, 2000, 2001, 2004, 2005, 2006, 2007, 2008, 2009 and 2010 were moderate (<0.25). Based on the thirty-one years average of 0.193, the turbulence level of Ikeja location can be said to be moderate and suitable for wind energy generation without overloading the wind turbine components

Performance Evaluation of Weibull Model

The adequacy and reliability of the Weibull based model used in this study was assessed using statistical test tools. These include the correlation coefficient between the actual wind speed and Weibull predicted wind speed, the root mean square error, chi-square test and the coefficient of efficiency of the Weibull model. The plot of monthly and seasonal variation of actual wind speed and Weibull predicted wind speed is as shown in Figure 4. The correlation coefficient between the actual data and weibull predicted data was determined to be 0.99. This implies that the Weibull model produces a good fit to the actual data. The chi-square test gave 100% while the root means square error was 0.0268. Also, the coefficient of efficiency of the Weibull model was determined to be 0.0026. The results obtained shows that there is a high level of agreement between the actual data and the Weibull predicted data with minima error. Therefore, it can be concluded that the 2-parameter Weibull model can adequately and reliably predict the wind situation at Ikeja location.

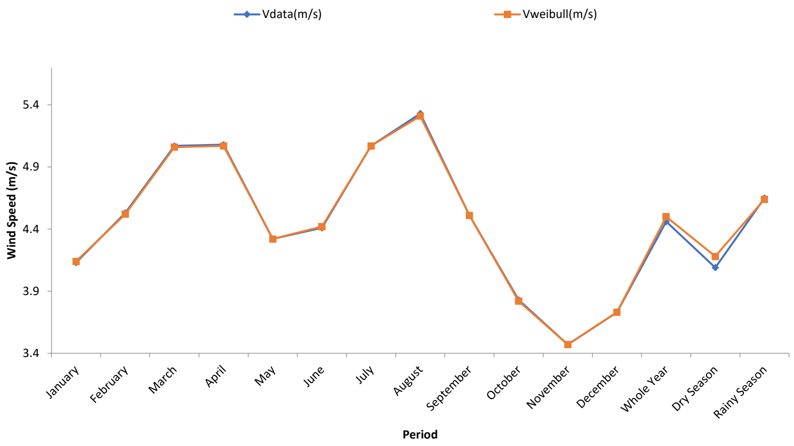

Figure 4. Monthly and seasonal variation of actual data and weibul predicted mean wind speed

Wind Power Density

Figure 5 shows the monthly and seasonal variation of wind power density estimated at hub heights of 10m, 50m. It could be observed from the plot that wind power density changed with months, season and hub heights. Monthly variation showed two peak points in March and August while minimum values of WPD were observed in October, November, December and January and May. At 50m height which was the reference height for wind power classification (Table 2), the WPD ranged between 116.3 W/m^2 and 423.3W/m^2 with annual average value of 257.85W/m^2. According to the international wind power classification shown in Table 2, the wind energy potential of the study area can therefore be remarkably described as fair in the months of March, April, and July belonging to power class 3. The wind potential is good in August belonging to power class 4 while it is marginal in February, May, June and September belonging to power class 2. The wind potential is remarkably poor in the months of January, October, November and December belonging to power class 1. Seasonally, the wind energy potential is marginal in rainy season belonging to power class 2 and poor during dry season belonging to power class 1. Based on the whole year assessment the wind potential at Ikeja is marginal belonging to power class 2. The result indicated that Ikeja location will be most suitable for standalone small to medium scale wind electricity generation.

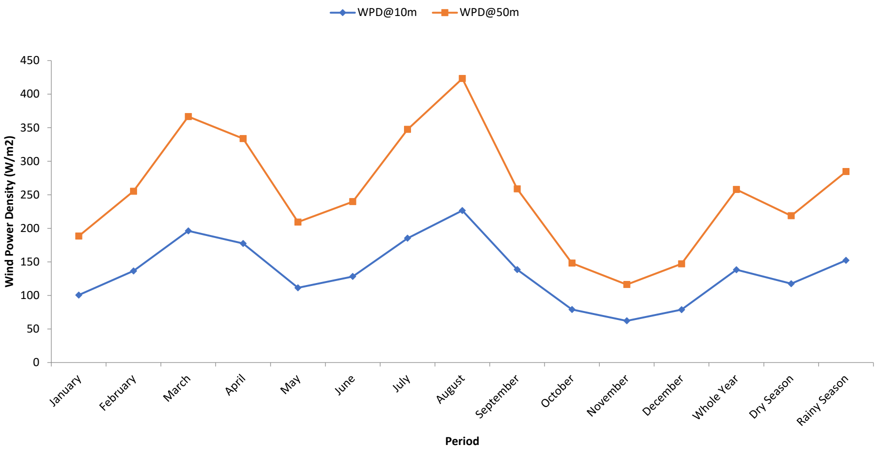

Figure 5. Monthly and seasonal variation of wind power density at different hub height

Maximum Energy Carrying Wind Speed and Most Probable Wind Speed

Figure 6 shows the monthly and seasonal variation of maximum energy carrying wind speed and the most probable wind speed estimated at different hub heights. The closer the value of these parameters to the rated speed (VR) of the wind turbine, the higher will be the conversion efficiency of the turbine. The technical specification presented in Table 1 showed that model turbine Suzzlon S88 had the lowest rated speed of 11.2 m/s which was relatively closer to the two speed parameters. This implies that the turbine will likely perform better than the other wind turbines considered. It could also be observed from the plot that the two speed parameters varied with months and seasons of the year. The values of maximum energy carrying wind speed and the most probable wind speed increased with increase in elevation or hub heights. At 90m hub height, the most probable wind speeds varied between 4.99 m/s and 7.64m/s with an annual average value of 6.37m/s. There were four months with values of most probable wind speed exceeding 7.0m/s. These are the months of March, April, July, and August representing months within the period of the rainy season. This implies that the wind electricity generation potentials will be maxima within those months. Also, there were four months with the value of most probable wind speed less than 6.0m/s at 90m hub height. These include the months of October, November, December and January, which are the first four months of the dry season. This observation likewise implies low wind electricity generation potential within those months. Seasonally, it could be observed that the value of most probable wind speed was higher during the rainy season compared to the dry season. This implies higher wind electricity generation potential during the rainy season compared to the dry season. The variation of maximum energy carrying wind speed follows similar trend as that of most probable wind speed. The values of maximum energy carrying wind speed at 90m height varied between 5.68m/s and 8.74m/s with an annual average of 7.4m/s. Those months with values exceeding 8m/s were March, April, July, and August while values below 7m/s were obtained in the months of October, November, December and January and May. This observation likewise implies higher wind electricity potential during rainy season compared to the dry season.

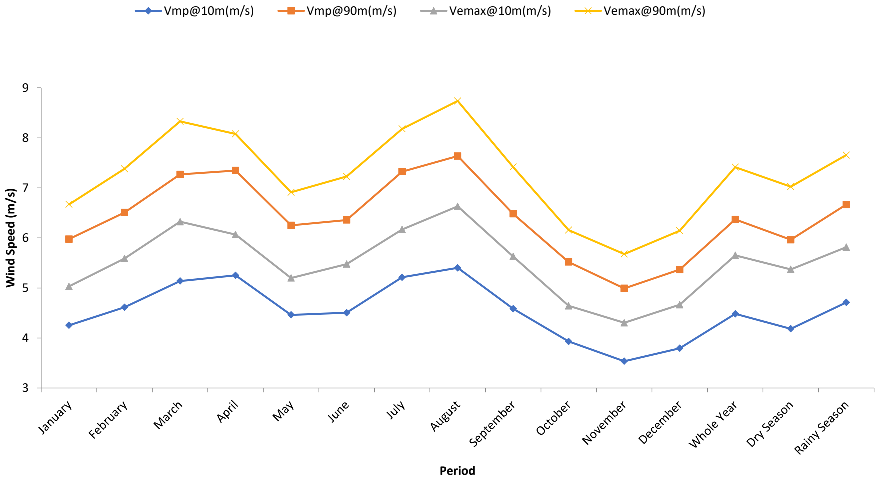

Figure 6. Monthly and seasonal variation of maximum energy carrying wind speed and most probable wind speed at different hub heights

Mean Power Output and Capacity Factor

The monthly and seasonal variation of mean power output was estimated based on the technical specifications and speed parameters of the model turbines highlighted in Table 2. The plot in Figure 7 shows that the mean power output and the capacity factor of the model turbines vary with months and season of the year. It could be observed from the plot that the variation of mean power output and capacity factor exhibited a similar trend. They both attained maximum values in March and August. They both dropoed to a minimum in October, November, December, January and May which are mostly months of the dry season except May which is month within the rainy season. The mean electrical power output from the model turbine varied between 289.99KW and 10.9KW while the capacity factors varied between 13.8% and 0.36%. Seasonally, the mean power output and the capacity factor of the model turbine were higher during the rainy season compared to the dry season. This implies that the wind turbines will generate more electrical power during the rainy season compare to the dry season. The turbine model Suzzlon S88 performed best under the wind regime having maximum mean power output and highest conversion efficiency.

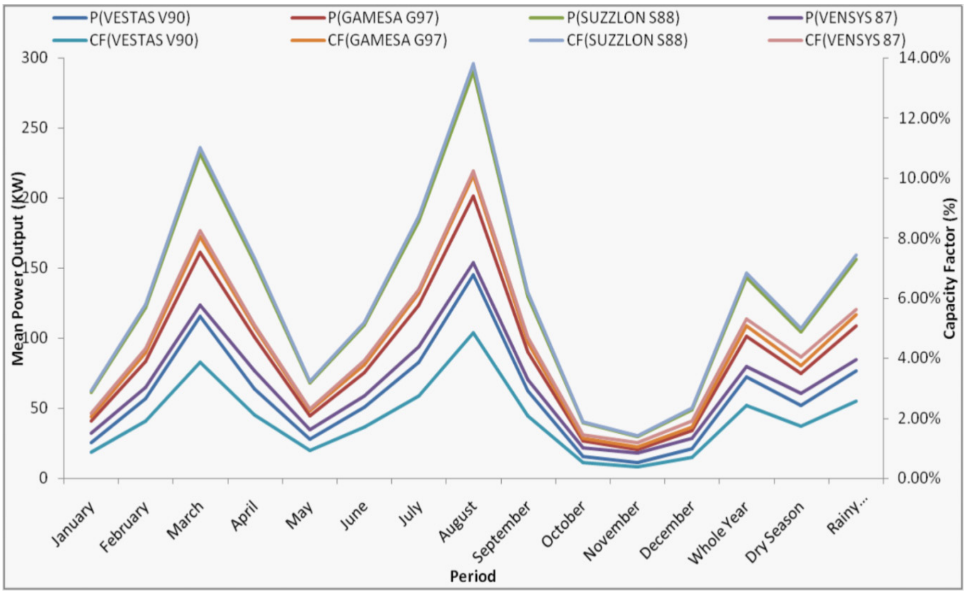

Figure 7. Monthly and seasonal variation of mean power output and capacity factor of the four model wind turbine

Total Annual Energy Production

The plot of annual energy production for the four different models of wind turbines is shown in Figure 8. It could be observed that the annual energy production differ for the four turbines models considered. The turbine model Suzzlon S88 was found to produce the highest total annual energy of 1,255,772KWh; this was followed by Gamesa G97 with annual production of 888,787KWh. Vensys 87 had total annual energy production of 697,652.7KWh while Vestas V90 turbine produced 635,126 KWh of electrical energy annually. Wind turbine model Suzzlon S88 performed best with highest annual energy production.

Energy Cost

The monthly and seasonal variation of energy cost per kilowatt-hour for the four turbine model considered is shown in Figure 9. It could be seen from the plot that the cost of generation of wind electricity per kilowatt-hour was inconsistent but varies with months and seasons of the year. The cost of wind electricity generation ranged between a minimum of \$0.11/KWh and maximum of \$2.39/KWh. The estimated cost of generation is higher than \$0.5/KWh in the months of January, May, October, November and December which are mostly months within the period of the dry session with the exception of May. The electricity generation cost is less than \$0.2/KWh in March, July and August which are

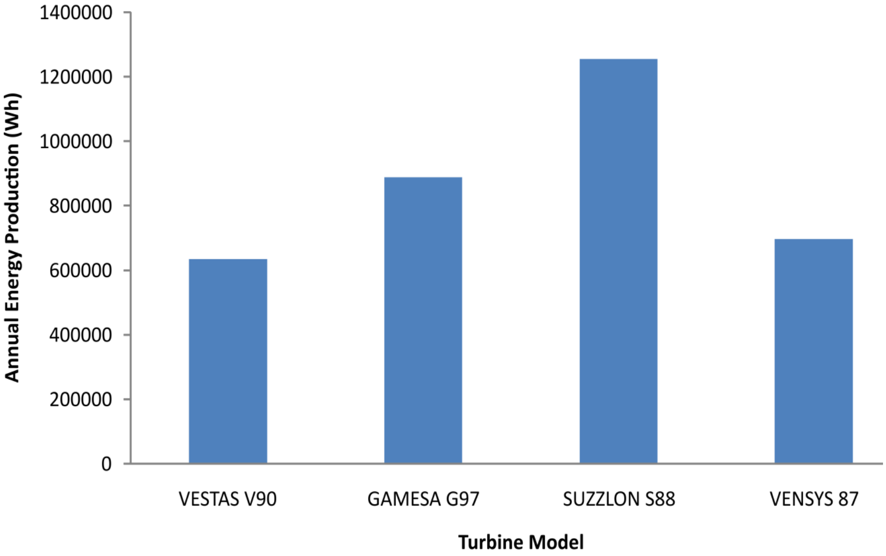

Figure 8. Annual energy production of the four model wind turbine

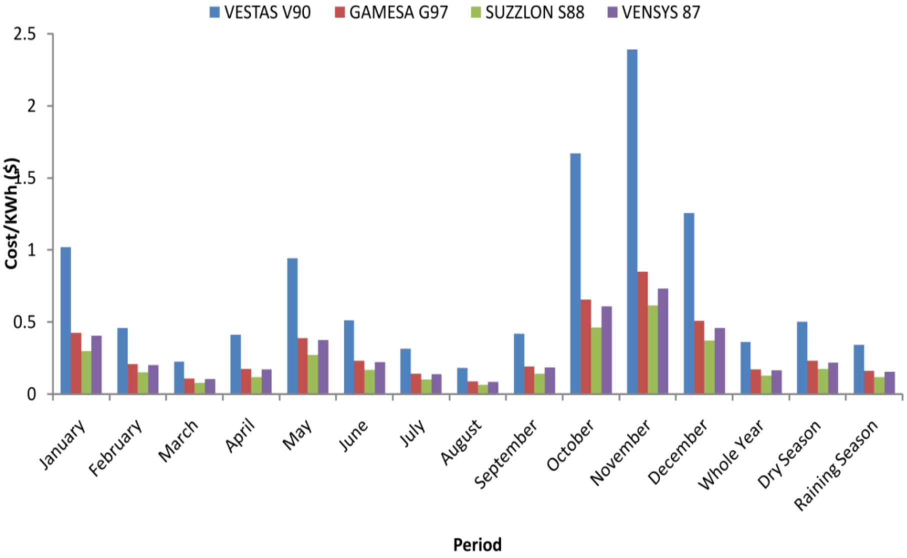

Figure 9. Monthly and seasonal estimate of energy cost ($/kWh) of four wind turbine models

months within the the rainy season. The Ikeja electricity tariff presently ranges between \$0.07/KWh and \$0.12KWh. Comparing the estimated energy cost with electricity tariff showed that wind electricity is yet to cost effective year round. Though the energy cost was lower than electricity tariff during some months of the year, the economic feasibility of wind energy development depends on its ability to generate electricity at a low operating cost throughout the year. The seasonal variation showed that the cost of wind electricity generation was higher during dry season compared to the rainy season. This indicates that the cost of wind electricity is relatively cheaper during the rainy season compared to the dry season. Improvement in the country economic situation and government intervention in the form of green subsidy, tax waiver and reduced interest on the loan, will go a long way in reducing the generation cost of wind electricity. Also, Nigeria electricity tariff is expected to increase biannually for years to come as contained in the country Multi-Year Tariff order 2.1 of 2015 (NERC, 2019). The expected increase in electricity tariff will further help in making the cost of wind electricity to be competitive with conventional electricity sources and subsequently, the wind energy might become economically feasible year round.

CONCLUSIONS

In this study, the wind electricity generation potential and its cost implication for Ikeja location were assessed using the two-parameter Weibull distribution function and PVC energy cost method. From the result obtained it can be concluded that;

i) The wind speed data shows good fit between actual data and Weibull predicted data confirming the adequacy and reliability of the Weibull model.

ii) The value of wind speed at 10m height ranges between 3.47m/s and 5.33m/s with annual average of 4.5m/s. While it has seasonal average value of 4.09m/s in dry season and 4.65m/s during the rainy season. While the Wind Power Density (WPD) at 50m hub height ranges between 116.3 W/m^2 and 423.3W/m^2 with annual average value of 257.85W/m^2.

iii) The location wind regime belongs to power class 2 with marginal potential for wind electricity generation.

iv) The location is suitable for small to medium scale stand-alone wind electricity generation.

v) The generation cost of wind electricity is not cost-effective year round when compared with the present Ikeja electricity tariff while the location is not economically feasible for large scale grid connected wind power generation.

RECOMMENDATION

Further study on the assessment of wind electricity generation potential of Lagos Island and the coast of Gulf of Guinea for comprehensive mapping is hereby recommended.

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