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Techno-economic Assessment of Wind Turbines in Nigeria

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ABSTRACT

Wind energy potentials of some selected high altitude and coastal areas in Nigeria are assessed for possible utilization for the generation of electricity. The main aim is to provide pragmatic insight that will enhance the investment in wind energy conversion systems in an optimal manner. The data used in this present study were obtained from the Nigeria Meteorological Agency, which includes average wind speeds per day of four locations across the country, measured at the anemometer height of 10 m over a period of 11 years. With the sites classified based on their wind power densities, the capacity factor estimation value was used to select the most suitable turbine for the selected sites, and the present value cost method was employed to estimate the unit cost of energy of the turbine at various hub-heights. The results obtained from this study reveal that Jos, Kano and Ikeja are economically viable as well as having excellent wind resources integration into the grid, while P/H is viable for a standalone application. The outcome of the study provides useful information that will aid renewable energy policymakers in Nigeria for wind energy development.

Keywords: Capacity Factor Estimation, Wind Turbine, Electricity Generation, Techno-economy
JEL Classification: C63

1. INTRODUCTION

Energy is among the essential needs of economic development (Babatunde et al., 2020; Oyedepo et al., 2012; Somefun et al., 2020), in meeting the world high energy demand. The significant sources of energy in use have been conventional fossil fuels (Mohammadi et al., 2014). The quest to cut down on the use of fossils due to their fast depletion, harmful environmental influences, unstable prices, as well as the daily increase in energy demand has motivated the need for alternative cleaner energy resources (Li et al., 2019; Somefun et al., 2019). In the recent years, the use of wind energy for the generation of electricity has gained more acceptance all over the world due to its default abundance, affordability, cleanliness, inexhaustibility and environmental friendliness (Adetokun et al., 2020). Other

advantages include the fact that its installation requires little or no maintenance and has no political or geographical boundaries. Among the renewable energy sources, wind energy is known for its fastest-growing characteristics in both developing and developed countries (Adetokun et al., 2018; Arıoğlu et al., 2015).

While developing countries are still striving in harnessing the abundance and environmental friendliness of the renewable energy resources, some developed countries like Germany, Spain, United States of America, China, and Denmark has proven its benefits and still expanding the generating capacity through renewable energy technologies. As at now, a more significant percentage of electricity is yet being generated using fossil fuels in Nigeria (Edomah, 2016). At present, the Nigeria electricity generation floats around 12.5GW

for all sources (thermal and hydro) with only 3.5GW to 5.0GW is typically available for onward transmission to the final consumer (Adekitan et al., 2018; Adesanya and Pearce, 2019; Adetokun et al., 2018). This present generating capacity is highly inadequate for a country that has a population of over 200 million (World meter, 2020). The massive shortage in electricity supply as compared with the people has led to higher energy poverty and low standard of living, most notably in the rural areas of the country (Njiru and Letema, 2018). In mitigating this challenge, there is the need to vigorously pursue an energy mix by way of harnessing the nation's available renewable energy resources, especially wind source.

The wind is an inexhaustible energy resource that can be used to produce a significant amount of energy to support a country's energy needs (Owusu and Asumadu-Sarkodie, 2016). Man has harnessed wind energy since inception through windmills. Today, wind energy can be utilized for both the non-grid and grid electricity applications (Budischak et al., 2013). The most crucial factor to be considered when siting a wind turbine is the wind speed (Marimuthu and Kirubakaran, 2014). Another decisive factor is the total annual electricity generation from the wind. However, wind resource varies from year to year, causing the wind energy forecast a delicate operation.

Assessing the wind energy production of a particular location requires, firstly meteorological measurement for a considerable period for an accurate prediction of the potential of energy available on that site (Hulio et al., 2017). Based on measured data, statistical methods are applied to describe the wind resource features, and then the wind power density available at the site is evaluated. The analytical tool mostly employed is the Weibull distribution function (WDF) because of its flexibility and simplicity. Besides, it is adequate for a large range of wind data (Badawi et al., 2019).

The possibility of generating electricity through the use of wind, in Nigeria, has been extensively reported in the open literature (Adaramola et al., 2014; Ajayi et al., 2014; Ayodele et al., 2018; Ohunakin et al., 2012; Oyedepo et al., 2012). Authors in reference (Oyedepo et al., 2012) explored wind features and its energy potential for three different locations in the South-Eastern part of Nigeria for 27 years of data at the height of 10 m. Performance of wind turbines for the generation of electric energy in the Southern zone of Nigeria was reported in (Adaramola et al., 2014). Investigation of the techno-economic viability of water pumping through the use of wind energy in the southern area of Nigeria was recorded in (Ayodele et al., 2018). Authors in (Ohunakin et al., 2012) analyzed cost estimate for wind turbines in generating electricity within six selected high altitude locations in Nigeria while authors in reference (Ajayi et al., 2014) assessed the techno-economic of wind turbines in generating electricity in ten areas in the southern zone of Nigeria.

In contrast to all the studies mentioned above which focused on identifying suitable locations, selecting an appropriate wind turbine and determining the unit cost of energy, this present study does not only identify suitable sites but also determine the effect of varying hub height on the unit cost of energy, thereby given economic insight in making a useful decision on the generation of optimal wind energy investment in Nigeria. The rest of this paper is structured as follows: section 2 presents the detail description of the method employed in this study, while Section 3 gives the result of the research, with discussion, and Section 4 concludes the paper with recommendations.

2. MATERIALS AND METHODS

2.1. Sites Description and Wind Data
The study covers four locations from four geo-political zones of the country, with each site representing each geo-political zones, as shown in Figure 1. Daily wind speed data on the selected areas, measured with a cue generator anemometer at the height of 10meter as obtained from the NIMET, Lagos, Nigeria. Table 1 summarizes the characteristics of the selected locations,

Figure 1: Map of Nigeria showing the six geo-political zones of the country
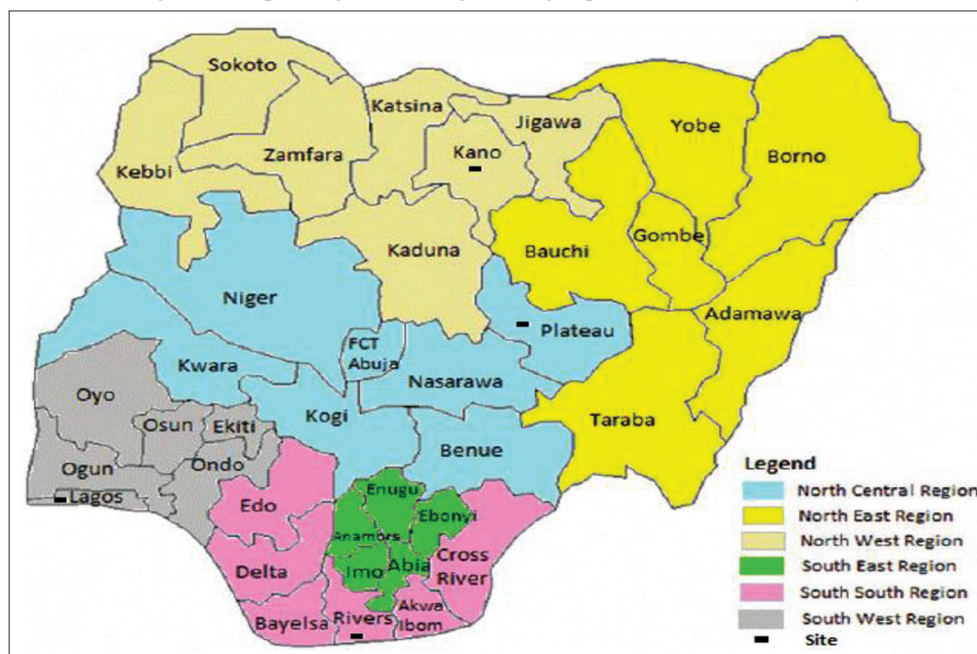
Table 1: Characteristics of the selected locations

Locations	Zone	Latitude (°N)	Longitude (°E)	Altitude (m)	Data period
Ikeja	South-West	6.35	3.20	-	2000-2010
P/H	South-South	4.78	7.0	465	2000-2010
Jos	North-West	9.92	8.9	1217	2000-2010
Kano	North-West	12.05	8.52	478	2000-2010

which includes geographical information of the sites together with the intervals of the data collections.

2.2. Modelling of Wind Speed

The two-parameter Weibull distribution is one of the most used probability distribution in wind-speed applications. The mathematical expression for the Weibull Probability Density Function, $f(V)$, and the Cumulative Distribution Function, $F(V)$, are given in equations 1 and 2 (Olatomiwa et al., 2016):

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

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

where; v, k and c represents the speed of wind (m/s), shape parameter, which is dimensionless, and scale parameter (m/s) respectively. The Weibull parameters can be estimated using different methods such as graphical method, maximum likelihood method, power density method, empirical technique *etc*. In this paper, the empirical approach is adopted because it requires less computation, and it is expressed using equations 3 and 4 (Olatomiwa et al., 2016):

$$k = \left[\frac{\sigma}{V_m}\right]^{-1.086} \tag{3}$$

$$c = \frac{V_m}{\Gamma\left(1 + \frac{1}{k}\right)} = \frac{V_m k^{2.6674}}{0.184 + 0.816 k^{2.73855}} \tag{4}$$

where; σ, V_m and Γ represents the standard deviation, mean wind speed and gamma function respectively.

$$\sigma = \sqrt{\frac{1}{n-1}\left(\sum_{i=1}^{n}(V_i - V_m)^2\right)} \tag{5}$$

$$V_m = \frac{1}{n}\sum_{i=1}^{n} V_i \tag{6}$$

and,

$$\Gamma(x) = \int_0^\infty e^{-t} t^{x-1} dt \tag{7}$$

Furthermore, another important parameter apart from the mean wind speed are the most probable wind speed (V_{mp}) and the wind speeds carrying maximum (V_{maxE}). These can be expressed as given in equations 8 and 9 (Rehman et al., 2012):

$$V_{mp} = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \tag{8}$$

$$V_{maxE} = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \tag{9}$$

The most probable wind speed corresponds to the maximum of the probability density function, while wind speed carrying the maximum energy is utilized in estimating the design of the wind turbine.

2.3. Wind Speed Modelling at Different Hub-height

Most times, the wind speed data available are measured at a height, which is different from that of the wind turbine. Consequently, the speeds of the wind are adjusted to the wind turbine hub-height as presented by the power-law expression given by (Dalabeeh, 2017):

$$\frac{V}{V_0} = \left(\frac{h}{h_0}\right)^\alpha \tag{10}$$

where; V_0 is the wind speed at the referenced height h_0, and V is the wind speed at extrapolating height, h. The exponent, α, is the site surface roughness coefficient; its typical values lie between 0.05 and 0.5. However, due to insufficient data to estimate the value, it is usually assumed to be 0.143 (Ohunakin et al., 2012), hence; the scale factor, c and shape factor, k, of the Weibull distribution will change in terms of the height based on the following equations (Dalabeeh, 2017):

$$\frac{c_h}{c_o} = \left(\frac{h}{h_0}\right)^n \tag{11}$$

$$n = \frac{0.37 - 0.088 ln(c_0)}{1 - 0.088 ln\left(\frac{h}{10}\right)} \tag{12}$$

$$\frac{k_h}{k_0} = \frac{1 - 0.088 ln\left(\frac{h_0}{10}\right)}{1 - 0.088 ln\left(\frac{h}{10}\right)} \tag{13}$$

where; k_0 and c_0 are the shape parameter and scale factor at a measured height h_0

2.4. Wind Power Density

The density of wind power is a measure of how much wind energy is available for conversion in each site by the turbine as expressed by equation 14 (Adaramola et al., 2014):

$$WPD = \frac{1}{2}\rho V^3 \left(W/m^2\right) \tag{14}$$

where ρ is the standard air density of the site, assumed to be 1.225kg/m³ (Olatomiwa et al., 2016). The *WPD*, according to the field measurement of the wind speed, can also be evaluated through Weibull distribution function given by equation 15 (Adaramola et al., 2014):

$$WPD = \frac{P}{A} = \int_0^{\infty} \frac{1}{2} \rho V^3 f(V) dv = \frac{1}{2} \rho C^3 \Gamma\left(\frac{k+3}{k}\right) \quad (15)$$

2.5. Output Power of the Capacity Factor and Wind Turbine

The average power output of a wind turbine is essential in the conversion system of wind energy because it serves as is a good pointer towards economics than the rated power. Its estimation in terms of the Weibull distribution is obtained from (Ayodele et al., 2016) as shown in equation 16:

$$P_{avr} = \int_{V_{ci}}^{V_{co}} P(V) f(V) dv \quad (16)$$

where $P(V)$ is the power curve of the wind turbine, $f(V)$ is the probability density function representing a fraction of duration of wind speed V_i, V_{co} is the cut-out wind speed and V_{ci} is the cut-in wind speed of the turbine. In a pitch-controlled turbine, the power curve can easily be approximated by a law of a parabola as expressed in equation 17:

$$P = \begin{cases} P_r = \dfrac{V_i^2 - V_{ci}^2}{V_r^2 - V_{ci}^2} & V_{ci} \leq V_i \leq V_r \\ P_r = \dfrac{1}{2} \rho A C_p V_i^3 & V_r \leq V_i \leq V_{co} \\ 0 & V_r \leq V_{ci} \, and \, V_i \geq V_{co} \end{cases} \quad (17)$$

where C_p, A, P_r and V_r represent the coefficient of performance, turbine swept area, rated power of the turbine and rated wind speed of the turbine.

From equation 17, equation 16 yields;

$$P_{avr} = P_r \left[\int_{Vci}^{V_r} \frac{V_i^2 - V_{ci}^2}{V_r^2 - V_{ci}^2} f(v) dv + \int_{V_r}^{V_{co}} f(V) dv \right] \quad (18)$$

Using integration by substitution, equation 18 becomes

$$P_{avr} = P_r \left[\frac{e^{-\left(\frac{V_{ci}}{c}\right)^k} - e^{-\left(\frac{V_r}{c}\right)^k}}{\left(\frac{V_r}{c}\right)^k - \left(\frac{V_{ci}}{c}\right)^k} - e^{-\left(\frac{V_{co}}{c}\right)^k} \right] \quad (19)$$

The Capacity Factor (C_f) of a wind turbine is the ratio of the average power output of the turbine to its rated power given as

$$C_f = \frac{P_{avr}}{P_r} \quad (20)$$

Hence, C_f is expressed as given in equation 21:

$$C_f = \frac{P_{avr}}{P_r} = \left[\frac{e^{-\left(\frac{V_{ci}}{c}\right)^k} - e^{-\left(\frac{V_r}{c}\right)^k}}{\left(\frac{V_r}{c}\right)^k - \left(\frac{V_{ci}}{c}\right)^k} - e^{-\left(\frac{V_{co}}{c}\right)^k} \right] \quad (21)$$

2.6. Econometric of Wind Energy System

The economic viability of a wind turbine is its ability to generate energy at an optimal cost. The cost of a wind turbine associated with the energy is a function of the site which includes the cost of civil work and installation (C_{civ}), the specific rated power cost of the turbine (C_{sp}), wind speed, operation and maintenance cost (C_{opm}), and turbine haulage cost (C_{th}). Equation (22) is used in calculating the PVC of energy, which is produced by the wind turbine (Ohuriakin et al., 2012).

$$PVC = I_{inv} + C_{opm}\left[\frac{1+i}{r-i}\right]\left[1 - \left(\frac{1+i}{1+r}\right)^n\right] - S_v\left[\frac{1+i}{1+r}\right]^n \quad (22)$$

where; I_{inv} is the investment cost of the wind turbine, i is the inflation rate assumed to be 8.4% [20], S_v is the interest rate assumed to be 13% [20], S_v is the scarp value taking to be 10% of investment cost, C_{opm} is assumed to be 25% of the investment cost of wind turbine and n is the lifetime of the turbine (20 years).

The total cost (C_T) of energy production from the grid-connected wind turbine is given in equation 23 as:

$$C_T = PVC + C_{civ} + C_{th} \quad (23)$$

where; C_{civ} and C_{th} are assumed to be 4% and 10% of the investment cost of the wind turbine. The investment cost of a turbine can be determined using equation 24

$$I_{inv} = P_r \times C_{asp} \quad (24)$$

where P_r is the rated power (kW) of the wind turbine and C_{asp} is the average specific cost per unit kW ($/kW). Table 2 presents the range of the average specific cost of the wind turbine which decreases as the rated power increases just as obtained in (Ayodele et al., 2016).

The unit cost of energy can be obtained using equation 25:

$$C_{unit} = \frac{C_T}{8760 \times P_r \times Cf \times n} \quad (25)$$

3. RESULTS AND DISCUSSION

Results obtained are presented and discussed in this section under different sub-headings. Sub-section 3.1 discussed the results obtained from the wind characteristics of the sites, while the viability of the site for the generation of electricity is presented in sub-section 3.2. In sub-section 3.3, the optimal selection of wind turbine for various sites is presented, and sub-section 3.4 focuses on the econometric of the sites for an optimum investment of wind power generation in Nigeria.

3.1. Wind Characteristics of Sites

The determined Weibull distribution parameters (k and c) and wind characteristics (V_{mp} and V_{maxe}) with respect to hub-heights are shown in Table 3. From Table 3, it can be seen that k varies widely from 1.92 at hub-height of 10 m (P/H) to 8.54 at hub-height of 90 m (Ikeja). Likewise, varies widely from 6.17 m/s at hub-height of 10 m (P/H) to 21.40 m/s at the hub height of 90 m (Jos).

Table 2: The cost of wind turbine

Wind turbine rated power P_r (kW)	Specific cost ($/kW)	Average specific cost (C_{asp}) ($/kW)
>20	2200–3000	2600
20–200	1250–2300	1775
>200	700–1600	1150

Table 3: The wind parameters

Location	Wind parameter	Hub-Height				
		10 m	30 m	50 m	70 m	90 m
Ikeja	k	6.89	7.63	8.03	8.31	8.54
	C	11.38	13.76	15.25	16.41	17.41
	V_{mp}	11.12	13.51	15	16.16	17.16
	V_{maxE}	11.81	14.19	15.68	16.84	17.84
	WPD	800	1416	1931	2409	2880
P/H	k	1.92	2.13	2.24	2.32	2.38
	c	6.17	7.96	9.14	10.1	10.93
	V_{mp}	4.21	5.91	7.02	7.92	8.69
	V_{maxE}	8.95	10.86	12.15	13.2	14.12
	WPD	200	386	559	733	912
Jos	K	3.35	3.71	3.9	4.04	4.15
	C	14.93	17.53	19.13	20.36	21.4
	V_{mp}	13.43	16.11	17.73	18.98	20.02
	V_{maxE}	17.17	19.69	21.27	22.49	23.53
	WPD	1957	3081	3960	4742	5446
Kano	K	3.49	3.86	4.07	4.21	4.33
	C	12.31	14.76	16.28	17.47	18.48
	V_{mp}	11.17	13.66	15.19	16.38	17.39
	V_{maxE}	14.02	16.45	17.96	19.16	20.17
	WPD	1084	1823	2421	2975	3507

Table 4: Wind power densities of the selected locations

Site	Average wind speed (m/s)	Wind power densities (w/m²)	Class	Remarks
Ikeja	10.64	800	7	Viable for grid integration
P/H	5.47	200	3	Viable for stand-alone application
Jos	13.40	1957	7	Viable for grid integration
Kano	11.07	1084	7	Viable for grid integration

The most probable wind speed variation is shown ranging from 4.21 m/s at a hub height of 10 m (P/H) to 20.02 m/s at a hub height of 90 m (Jos), while the wind speed that carries the optimum energy is lowest at P/H (8.95m/s) and highest at Jos (23.53 m/s) at hub-height of 10m and 90 m respectively.

It is also seen from the results that Ikeja has the highest k throughout the period, while PH has the least. This high value of the shape parameter can be attributed to steady wind speed in Ikeja compared to P/H. Likewise, the table depicts Jos as having the highest c, while P/H has the least, and this results from the high altitude of Jos as compared to P/H.

Similarly, the variation of WPD with hub height is also shown in Table 3 and, based on which it could be inferred that the WPD is directly proportional to hub-height. At the 50 m hub-height, WPD of Ikeja, P/H, Jos and Kano increased by 141%, 180%, 102% and 123% respectively; while at a hub-height of 90 m, the increment is 260%, 356%, 178% and 224% respectively. This high increase is because the generated power by the wind turbine is directly proportional to the cube of its wind speed, hence; it is advisable for the wind turbine to be mounted at high hub height to maximize the potential of the wind speed of the site.

3.2. Estimation of Wind Power Potential of Site

Table 4 shows the densities of the wind power for the sites according to the data for the period under consideration and classified according to the standard as presented by NREL (Ayodele et al., 2016). From Table 4, it is clearly seen that Ikeja,

Jos and Kano have an average wind speed of 10.64 m/s, 13.40m/s and 11.07 m/s respectively, which are associated with the wind power densities of 800 w/m^2, 1957 w/m^2 and 1084 w/m^2. In accordance with NREL definition, these sites are associated with class 7, which shows that their viability for grid power integration. P/H belong to class 3, which is required for the application of the standalone wind power like water pumping battery charging etc., but not viable for grid-intertied application. However, at 50 m hub-height, P/H becomes a class 7 wind power as could be deduced from Tables 3 and 4, thus making it viable for grid integration.

3.3. Estimating the Capacity Factor of the Wind Turbine

Although the best match for a site is to design a wind turbine for a particular location, However, this may be time-consuming and frustrating (Ayodele et al., 2016). Hence, the need to device a means of utilizing an off-the-shelf turbine that is available in the market. In this case, the capacity factor method is employed in selecting the wind turbine. Table 5 summarizes the characteristics of wind turbine considered for selection in this study, with five different models of turbine considered.

According to Nelson and Starcher (2013), any wind turbine with CF less than or equal to 0.25 is not in any way suitable for the integration of the grid. Also, the wind turbine with CF, which is in excess of 0.25 is the best for any given location. The response of the wind turbines with respect to areas, and the capacity factor, is given in Table 6. Table 6 shows that at hub-heights between 10 m to 20 m, Jos is the best location and GE/900s turbine is the best turbine because it has the highest CF (0.74–0.83). Also, for a hub height between 50 m and 90 m, Ikeja is the best location with GE/900s turbine selected as the best turbine because it matches the wind regime (≥0.25) of all the sites, except for P/H at hub-height of 10 m.

All the wind turbines considered matches the wind regime for both Jos and Kano sites. Wind turbine V42 matches the wind regime of Ikeja and P/H at hub-height of 50 m and 70 m respectively, while V52, V80 and N80/2500 match it at hub-height of 30 m respectively.

Also revealed in Table 6 is the variation of hub-height with CF for GE/900s turbine. It is noticed that as the in hub-height increases from 30m to 50m, there is a corresponding increase in CF with 17.57%, 26.67%, 1.20% and 9.33% for Ikeja, PH, Jos and Kano respectively. Again, increasing the hub-height from 50m to 70m

Table 5: Wind turbine characteristics

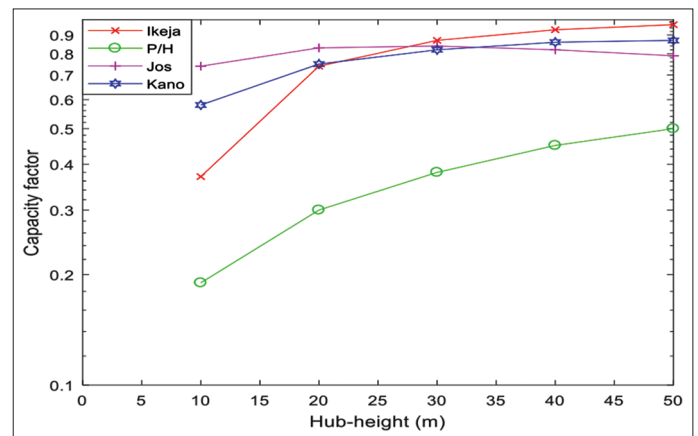| Turbine Model	V_{ci} (m/s)	V_{co} (m/s)	V_r (m/s)	Rated output (*kW*)	Rotor diameter (*m*)	Expected life (year)
V42	4	25	17	600	42	20
V52	4	25	16	850	52	20
V80	4	25	15	2000	80	20
GE/900s	3	25	13	900	55	20
N80/2500	4	25	14	25000	80	20

Table 6: Estimated wind turbine CF with respect to sites and hub-heights

Location	Turbine model	Capacity factor with varying hub-heights				
		10 m	30 m	50 m	70 m	90 m
Ikeja	V42	0.06	0.20	0.38	0.55	0.68
	V52	0.10	0.30	0.52	0.69	0.79
	V80	0.15	0.44	0.67	0.80	0.87
	GE/900s	0.37	0.74	0.87	0.93	0.96
	N80/2500	0.24	0.60	0.79	0.88	0.93
P/H	V42	0.09	0.16	0.22	0.26	0.31
	V52	0.11	0.19	0.25	0.30	0.35
	V80	0.13	0.21	0.28	0.34	0.39
	GE/900s	0.19	0.30	0.38	0.45	0.50
	N80/2500	0.15	0.24	0.32	0.38	0.44
Jos	V42	0.50	0.64	0.68	0.69	0.68
	V52	0.56	0.69	0.73	0.73	0.72
	V80	0.62	0.74	0.77	0.77	0.74
	GE/900s	0.74	0.83	0.84	0.82	0.79
	N80/2500	0.68	0.79	0.81	0.80	0.77
Kano	V42	0.30	0.47	0.58	0.65	0.69
	V52	0.36	0.54	0.65	0.71	0.75
	V80	0.43	0.61	0.71	0.77	0.80
	GE/900s	0.58	0.75	0.82	0.86	0.87
	N80/2500	0.50	0.68	0.77	0.81	0.84

Figure 2: Variation of the capacity factor for different hub-heights for the investigated sites

results in an increase in CF of 6.90%, 18.42%, and 4.88% for Ikeja, P/H and Kano respectively with a decrease of 2.38%recorded for Jos. This shows that the optimum hub-height for Jos is 50m. It is thus deduced from this result that sites located in coastal regions are more favourable in terms of hub-height variation than high-altitude sites. Therefore, the variation of CP with respect to the difference in hub-heights, for all the investigated sites, is as shown in Figure 2.

3.4. Econometric of Wind Turbine

Using GE/900s as a test case, the unit cost of energy ($/kWh), for the various sites, with respect to hub height, is presented in Figure 3. From the figure, it can be seen that the cost associated with the electricity generated by the turbine at Jos decreases as in hub-height increases from $0.039 kWh at h=10 m to $0.034 kWh at h=50 m. Further increase in turbine height from h=50m culminated into increase cost ($0.035 kWh and $0.037 kWh at h=70 m and h=90 m respectively). This further confirms the decrease in CF and also shows that the optimum hub-height for the favourable cost of electricity generation is 50m for Jos. Furthermore, it is revealed in the figure that the increase in hub height for Ikeja, P/H and Kano is accompanied by a decrease in the cost of electricity generation. At h=90 m, Ikeja has the least cost ($0.030 kWh), followed by Kano ($0.033 kWh) and then P/H having ($ 0.17 kWh).

Figure 3: Cost of energy with respect to different hub-height
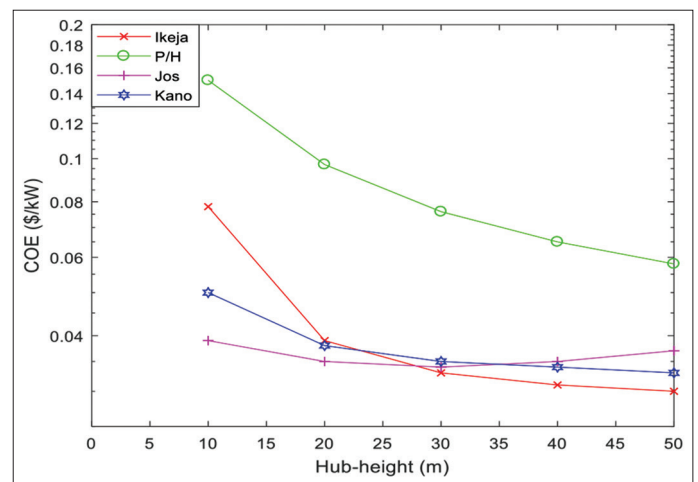
4. CONCLUSION

The economic, as well as potential viability of generating electric energy through the use of wind energy conversion system in some selected coastal regions (Ikeja and P/H) and high-altitude regions (Jos and Kano) in Nigeria, are examined. It is established that the average wind speeds for Jos, Ikeja, P/H and Kano are 13.40 m/s, 10.64 m/s, 5.47 m/s and 11.07 m/s respectively, while wind power densities of 1957 W/m^2, 800 W/m^2, 200 W/m^2 and 1084 W/m^2 respectively; all at the hub height of 10 m. Result obtained from this study also identified Jos, followed by Kano and Ikeja as sites having excellent wind resources, which makes these locations economically viable for grid integration but may be considered for standalone applications as well.

It is also obtained from the study that GE/900s wind turbine is the most suitable for all the sites considered as a result of its high CF values throughout the considered hub-height. However, the analysis of the economic implications on the turbine system shows that the cost for kWh of electricity reduces as the hub height increases, except for Jos that has 50 m as optimal hub height. The increase in the hub height eventually culminated into the cheap and affordable cost of electricity, compared to that of the grid. The least cost per kWh was recorded at Ikeja ($0.030 kWh at 90 m), followed by Kano ($0.033 kWh at 90 m), then Jos ($0.034 kWh at 50 m) and P/H ($0.058kWh at 90 m). With the newly adopted electricity tariff in Nigeria ($0.071 kWh for residential and $ 0.115 kWh), then at the official exchange rate of USD1:00 to NGN362:00, generation of electricity via wind energy conversion systems is more economically viable at locations like Jos, Ikeja and Kano, compared to the traditional grid supply.

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