Investigation of Wind Energy Resource Potential in Six Nigerian Locations for Power Generation

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Abstract

The Weibull distribution model has been employed in analyzing a ten year wind data from six chosen locations in Nigeria, three each from northern and southern settlements. The annual mean wind speeds in Sokoto, Bauchi and Lokoja are 4.33, 4.37, and 4.52m/s, respectively, while those of Owerri, Portharcourt and Abeokuta are 3.25, 3.27 and 2.76m/s respectively. The power densities on the annual scale in Sokoto, Bauchi and Lokoja are 49.14, 59.56 and 69.94W/m^2, respectively, whereas those of Abeokuta, Owerri and Portharcourt are 14.22, 25.77 and 23.76W/m^2 respectively. Therefore, the wind resources in most parts of Northern Nigeria is suitable for medium scale electric power generation while wind resources in most parts of southern Nigeria is only suitable for water pumping applications.

Keywords: Energy Density, Weibull Factor, Power Density, Maximum Energy, Northern and Southern Nigeria.

1 Introduction

The ever-increasing and incessant global and national overdependence on conventional energy resources for grid electricity generation, coupled with the inherent consequences such as pollution and environmental degradation, is necessitating increased attention and investments in alternative and sustainable energy sources for distributed power generation. Wind energy is gaining increased global attention due largely to its cleanliness, abundance and devoid of pollutant emissions like their conventional counterparts (Bedoud et al, 2016). According to Global Wind Energy Council (2011), wind power installations are almost becoming widespread, with a capacity of about 6.1GW in1996. This expressed a geometric jump to about 237.7GW in 2011, with Egypt, Morocco and Tunisia having shared capacities of about 550, 291 and 114MW, respectively. Also, renewable energy sources contributed renewable 23.7% electricity generation in 2015, of which 2.2% came from wind (Tank et al, 2016).

Studies have revealed high prospect of wind energy resource and possible exploitation and utilization in Nigeria. Effective deployment of wind energy technology in a chosen location depends solely on good understanding of accurate wind characteristics for the location (Ojosu and Salawu, 1990; Anyanwu and Iwuagwu, 1995; Asiegbu and Iwuoha, 2007). Average wind speed at the location influences greatly the choice or otherwise of wind turbine design for exploiting power at the location (Anyanwu and Ogueke, 2003; Ucar and Balo, 2009). Oyedepo et al (2012) analyzed the wind data and potential for three Nigerian cities, namely, Onitsha, Enugu and Owerri. Pobočíková et al (2018) stated that optimal location selection for wind turbine installations is of prime consideration to the optimization of cost/benefit ratio. Hence, precise evaluation of wind resources is cardinal in locating a favourable site for exploiting wind power (Al-Nhoud and Al-Smairan, 2015). Most reference wind data are available at low altitudes between 10-30m, but can be extrapolated to cover data at high altitudes (Uchida, 2018). He proposed a two-step vertical extrapolation technique for extending such data to high altitudes typical of offshore locations. Tank et al (2016) modelled wind energy conversion system using TRNSYS and generated wind energy generation potential maps for 30 Indian states using the weather, turbines and energy conversion parameters. They identified wind turbine power curves at different speeds, good wind speed distribution at a location as well as prevailing wind speed strength as factors that determine energy generation by wind energy generators. However, investigations on wind characteristics and potential covering many locations in Nigeria are not adequate to date, consequently, the current investigation, premised on the fact that investments on wind energy facility depends on sound decisions based on wind resource potential, which is location specific. Therefore, this is an extended study set at evaluating the wind resource potential for energy exploitation in six selected locations in Nigeria.

2 Estimation of wind energy potential

The wind data of six locations in Nigeria, spread across the six geographical regions of the country, were sourced from the Nigerian Meteorological Agency (NIMET), Oshodi, Lagos, for a period of ten years, spanning 2001 to 2010 and analyzed using the Weibull probability density function (PDF). According to Al-Buhairi and Al-Haydari (2012), the Weibull PDF is defined as:

$$f(s,k,c) = \left(\frac{k}{c}\right)\left(\frac{S}{c}\right)^{k-1} exp\left[-\left(\frac{S}{c}\right)^{k}\right] \quad 1$$

The probability that wind speed can be observed is given by the function, $f(s,k,c)$, defined by the speed s, dimensionless shape factor k , scale parameter c.

The cumulative distribution is expressed as (Qin et al, 2012; Bedoud et al, 2016):

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

All the parameters $s, k \; and \; c$ are greater than zero.

The shape (k) and scale (c) factors are the two parameters of Weibull PDF and are evaluated, respectively as (Oyedepo et al, 2012; Kumar and Gaddaba, 2015)

$$k = \left(\frac{\sigma}{S_m}\right)^{-1.086} \quad 3$$

$$c = \frac{S_m}{\Gamma\left(1+\frac{1}{k}\right)} \quad 4$$

σ in Eq.3 is the standard deviation (SD) and S_m is the mean wind speed while Γ in Eq.4 is the gamma function. The SD approach according to Kwon (2010) gives better result than other methods.

The above parameters, S_m (mean wind speed) and σ (SD), are expressed, respectively as (Al-Buhairi and Al-Haydari (2012); Nze-Esiaga and Okogbue, 2014):

$$s_m = c\Gamma\left(1+\frac{1}{k}\right) \quad 5$$

$$\sigma = c\left[\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right]^{\frac{1}{2}} \quad 6$$

The gamma function is defined using the Stirling approximation of (x) as (Kumar and Gaddaba, 2015):

$$\Gamma(x) = \int_0^\infty \tau^{x-1} e^{-\tau}\, d\tau \quad 7$$

Where $\tau = \left(\frac{s}{c}\right)^k$ and $\frac{s}{c} = \tau^{x-1}$; $x = 1 + \frac{1}{k}$

The mean speed can be written as:

$$S_m = 0.8525 + 0.0135k + e^{-\{2+3(k-1)\}} \quad 8$$

While the Wiebull scale factor is expressed as:

$$c = \frac{S_m k^{2.6674}}{0.184 + 0.816 k^{2.73855}} \quad 9$$

Two important parameters for wind energy estimation are the most probable and maximum energy wind speeds, defined by Bedoud et al (2016), respectively as:

$$S_F = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \quad 10$$

$$S_E = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \quad 11$$

According to Souloukngа et al (2017), and considering the Weibull model, the wind power density is given as:

$$P_D = \frac{\rho c^3 \Gamma\left(1+\frac{3}{k}\right)}{2} \quad 12$$

Where P_D is the wind power density, and ρ is is the density of air at the installation location.

And the mean energy density $E_{D,}$ is expressed as (Paul et al, 2012; Kumar and Gaddaba, 2015; Souloukinga et al, 2017):

$$E_D = \frac{\rho c^3 \Gamma\left(1+\frac{3}{k}\right)t}{2} \qquad 13$$

Where t is the time elapsed over a given period.

According to Illinca et al (2003), the Pacific Northwest Laboratory (PNL) wind power scheme has the following classifications: $P_D \leq 100$ (class1), $100 < P_D \leq 150$ (class2), $150 < P_D \leq 200$ (class3), $200 < P_D \leq 250$ (class4).

3 Results and Discussion

The calculated annual mean wind parameters for the study locations at a height of 10m are as presented in table 1.

Table 1: Annual mean wind parameters

Parameter	**Sokoto**	**Bauchi**	**Lokoja**	**Abeokuta**	**Owerri**	**PH**
Mean Wind Speed (Vm)	4.33	4.37	4.52	2.76	3.35	3.27
Shape Factor (K)	11.60	4.86	3.99	6.06	5.75	5.98
Scale Factor [c]	4.46	4.77	4.99	2.97	3.62	3.52
Most Probable Wind Speed (VF)	4.43	4.55	4.64	2.88	3.50	3.41
Maximum Energy Wind Speed (VE)	4.52	5.12	5.52	3.11	3.81	3.69
Mean Wind Power Density (PD)	49.14	59.56	69.94	14.22	25.77	23.67
Mean Energy Density (ED)	436.10	596.71	753.93	135.63	229.23	239.94

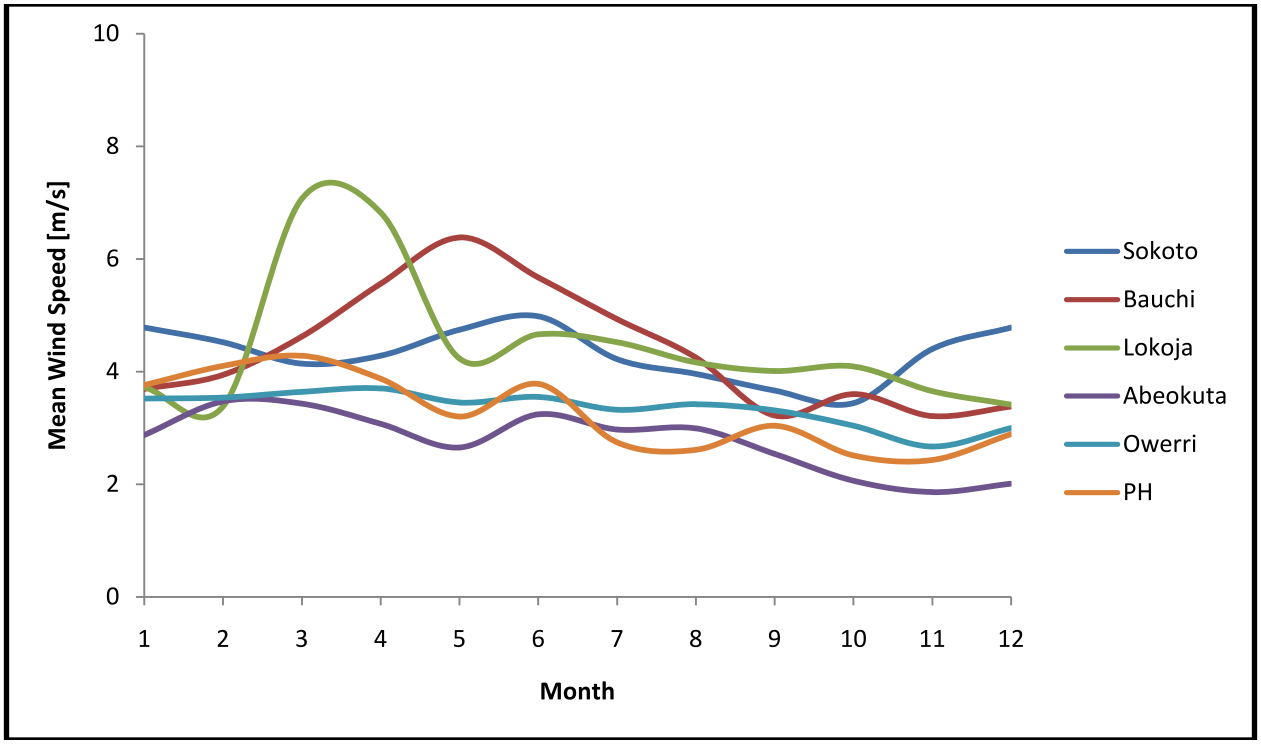

Fig. 1: Mean wind speed variation for all six study locations.

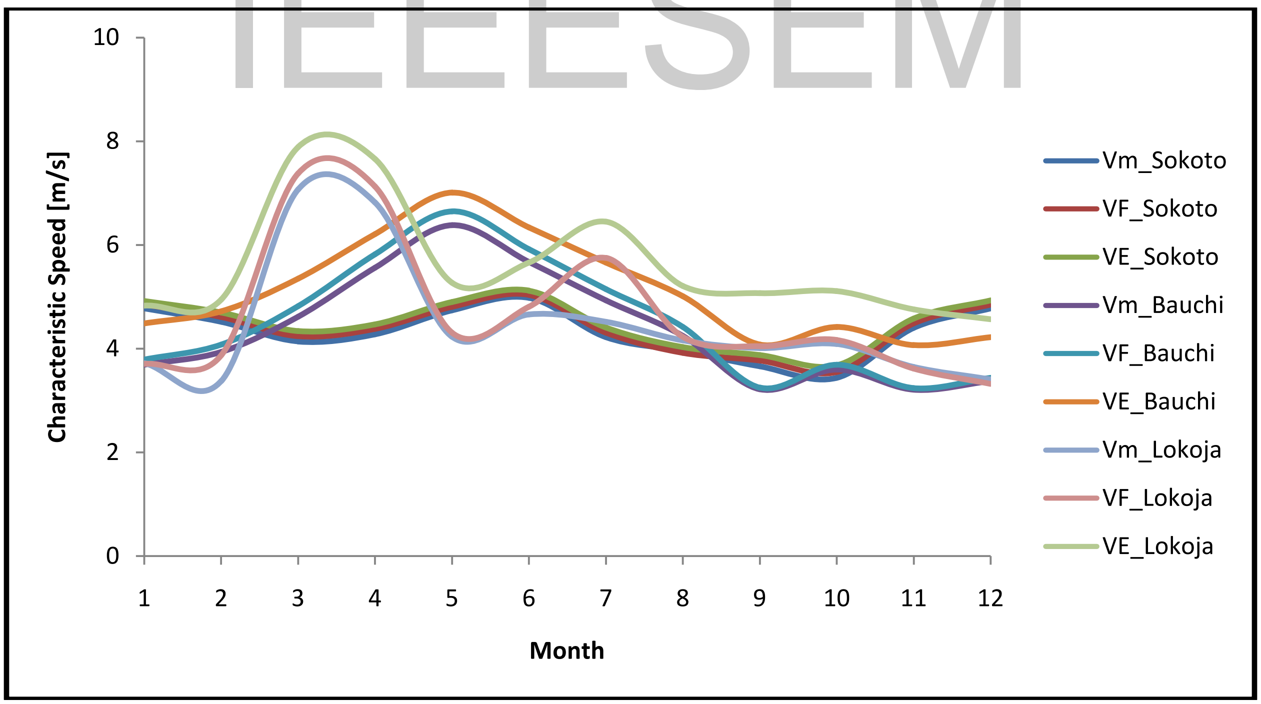

Fig. 2: Variation of characteristic speeds for Sokoto, Bauchi and Lokoja

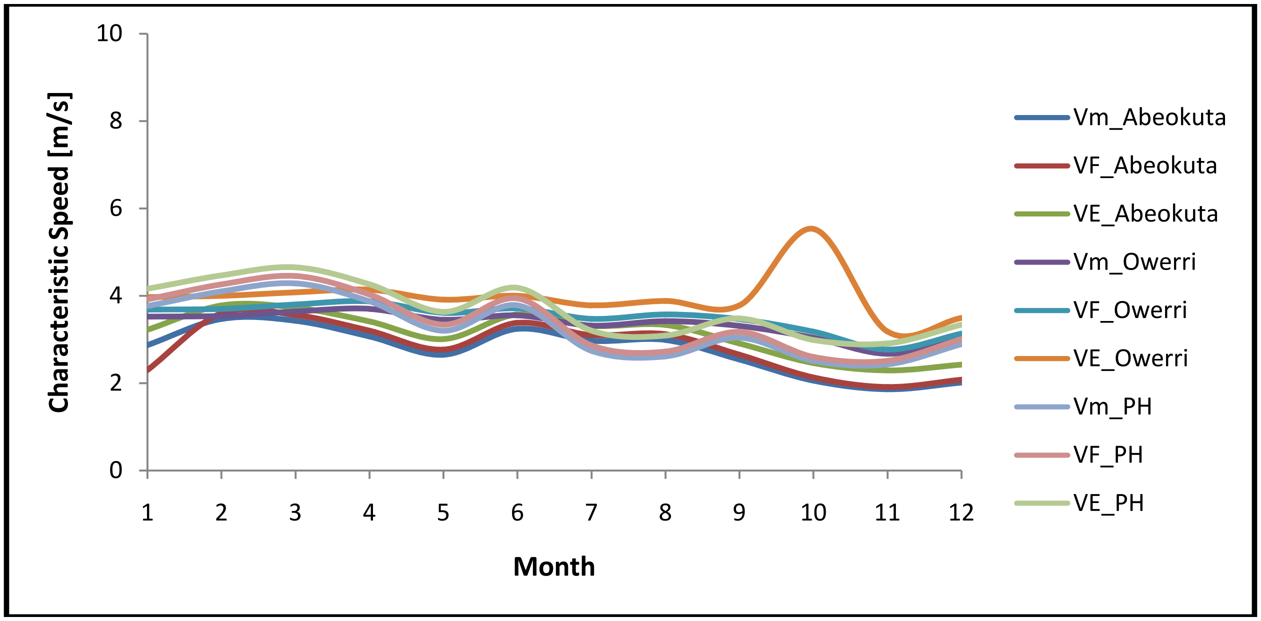

Fig. 3: Variation of characteristic speeds for Abeokuta, Owerri and Portharcourt

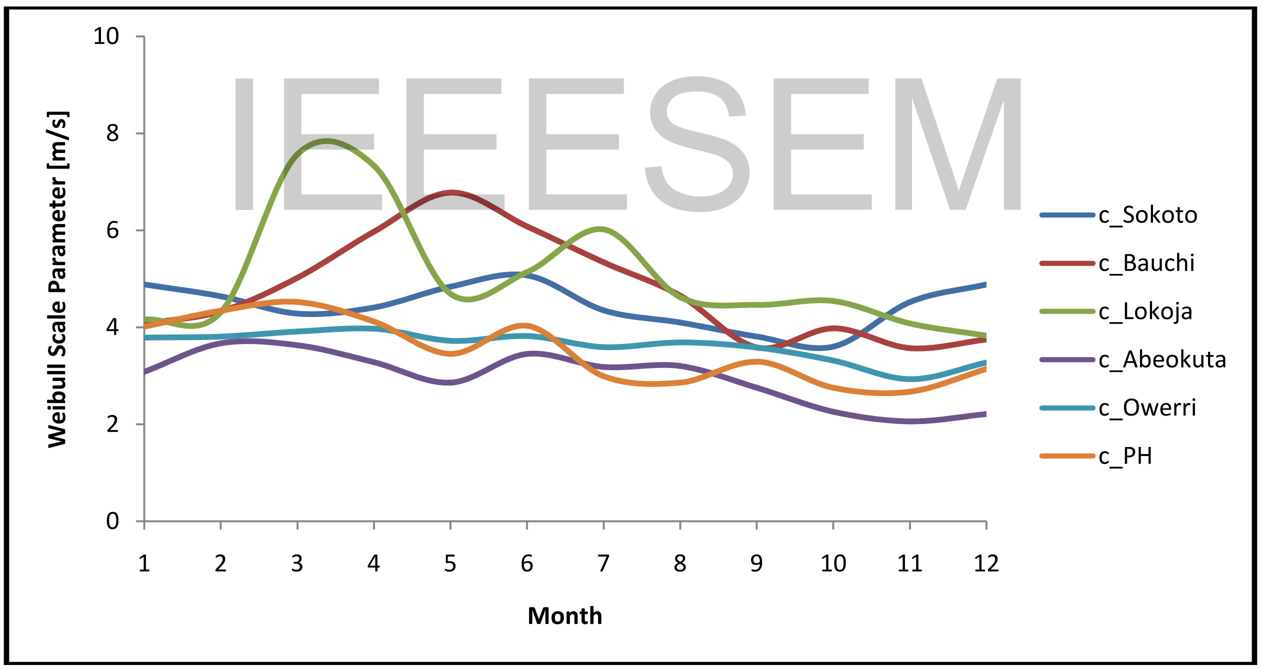

Fig. 4: Variation of Weibull scale factor for all six study locations

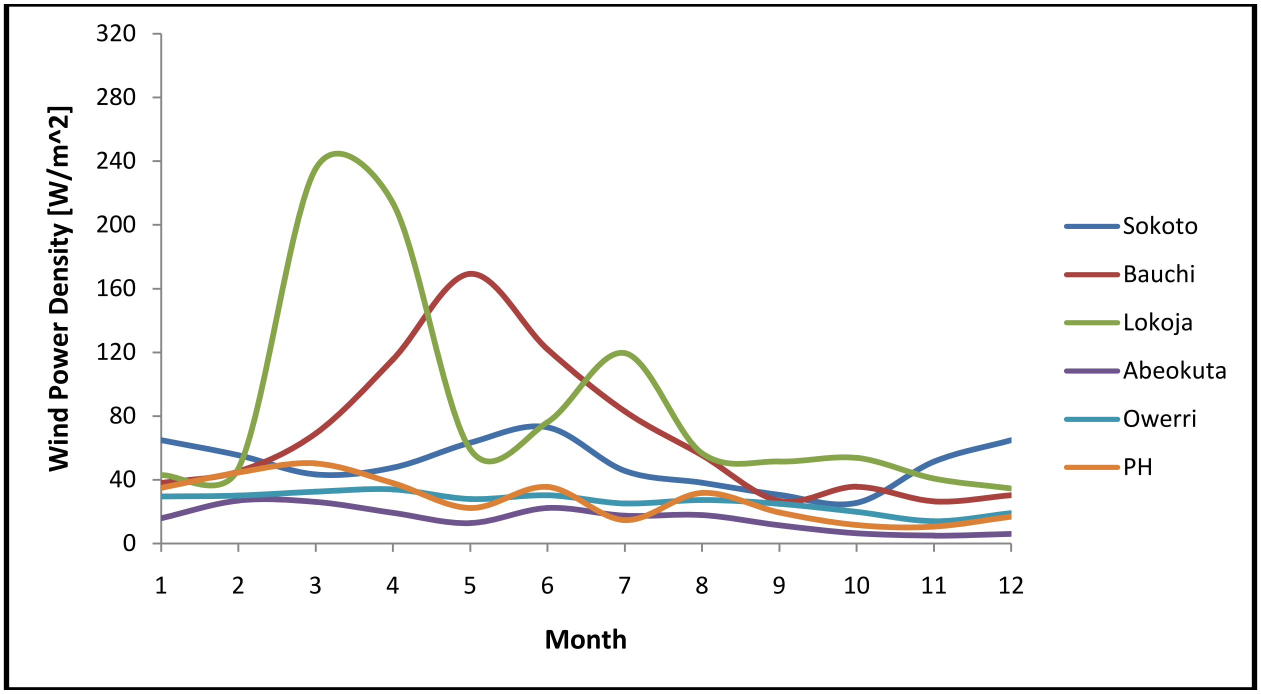

Fig. 5: Variation of mean wind power density for all six study locations

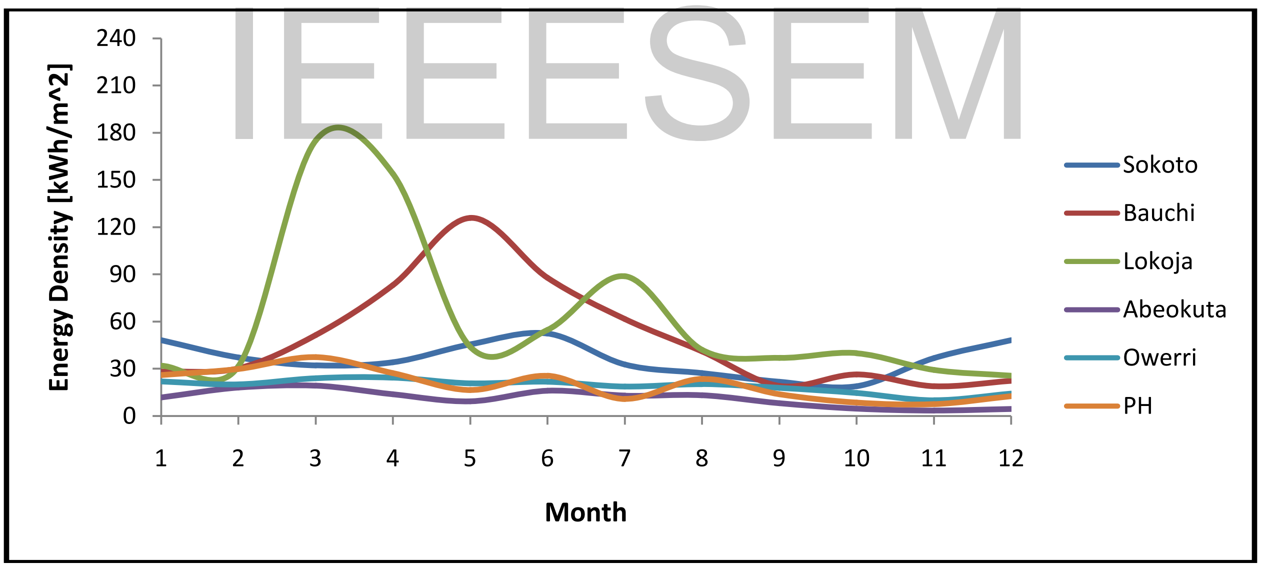

Fig. 6: Variation of wind energy density for all six study locations

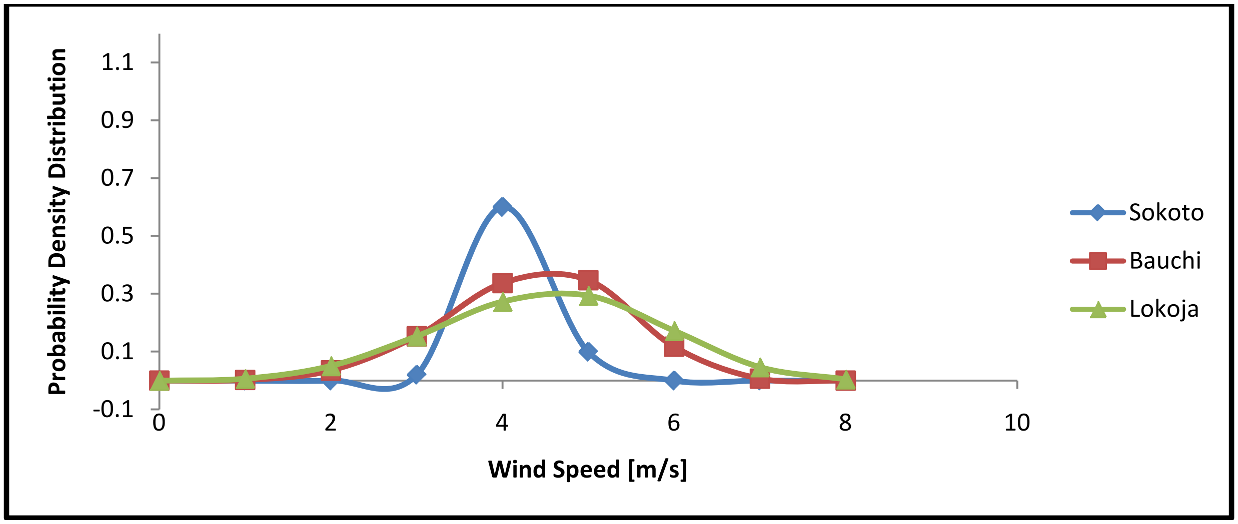

Fig 7: Annual wind probability distribution for Sokoto, Bauchi and Lokoja.

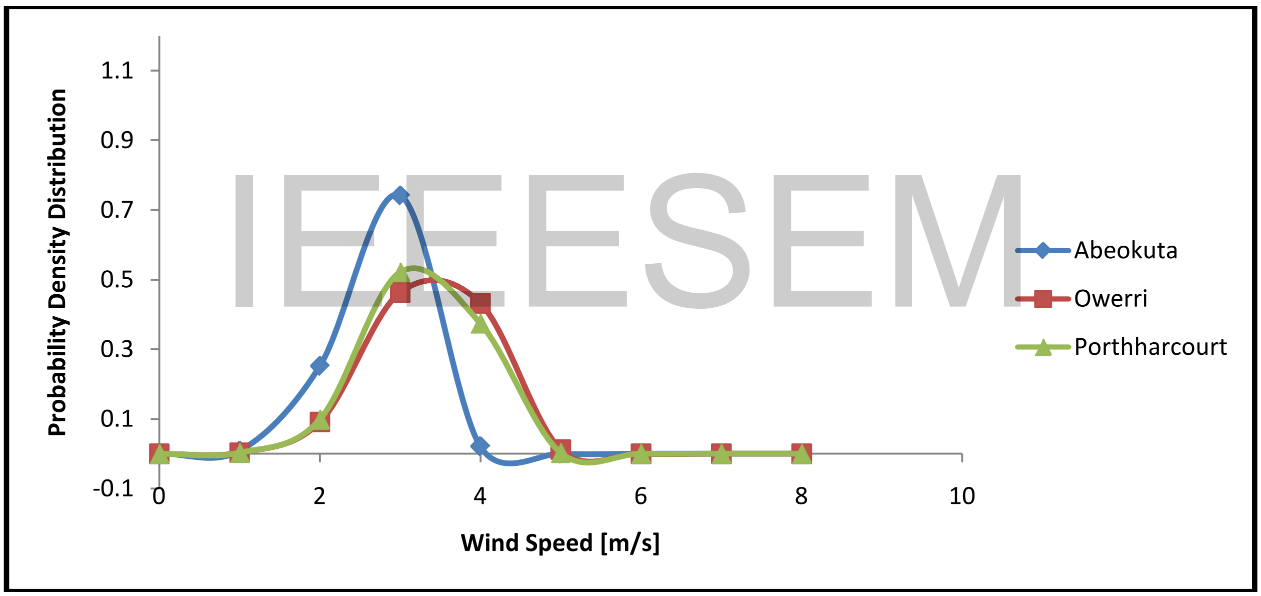

Fig 8: Annual wind probability distribution for Abeokuta, Owerri and Portharcourt.

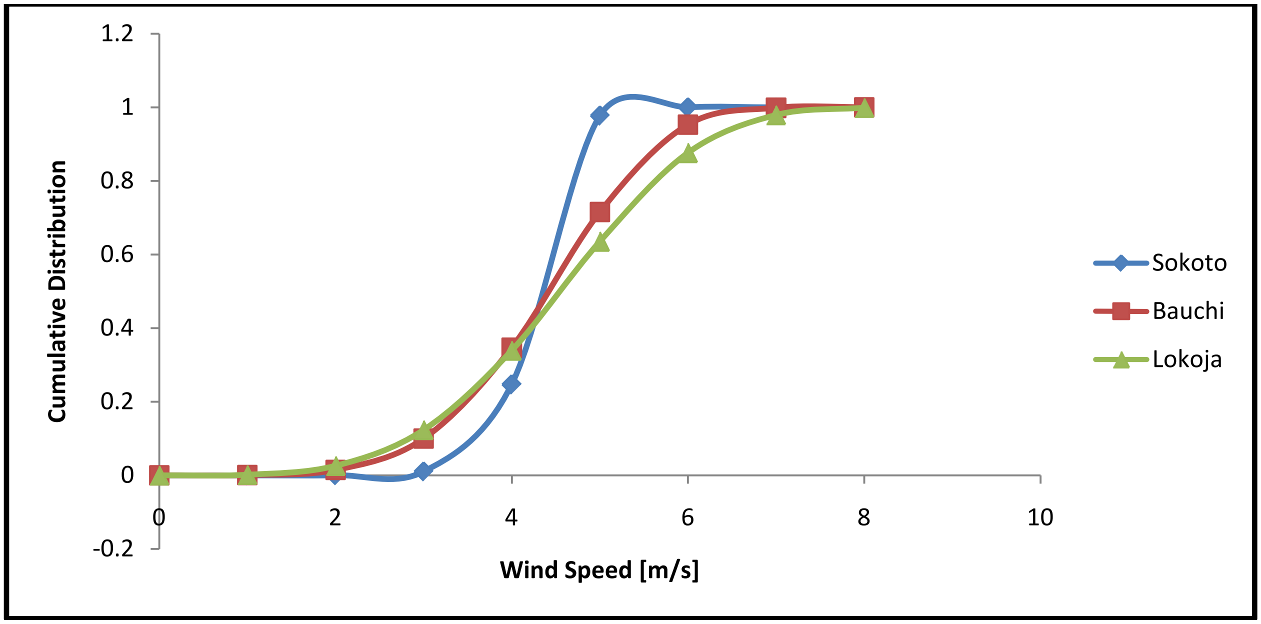

Fig 9: Annual wind cumulative probability distribution for Sokoto, Bauchi and Lokoja.

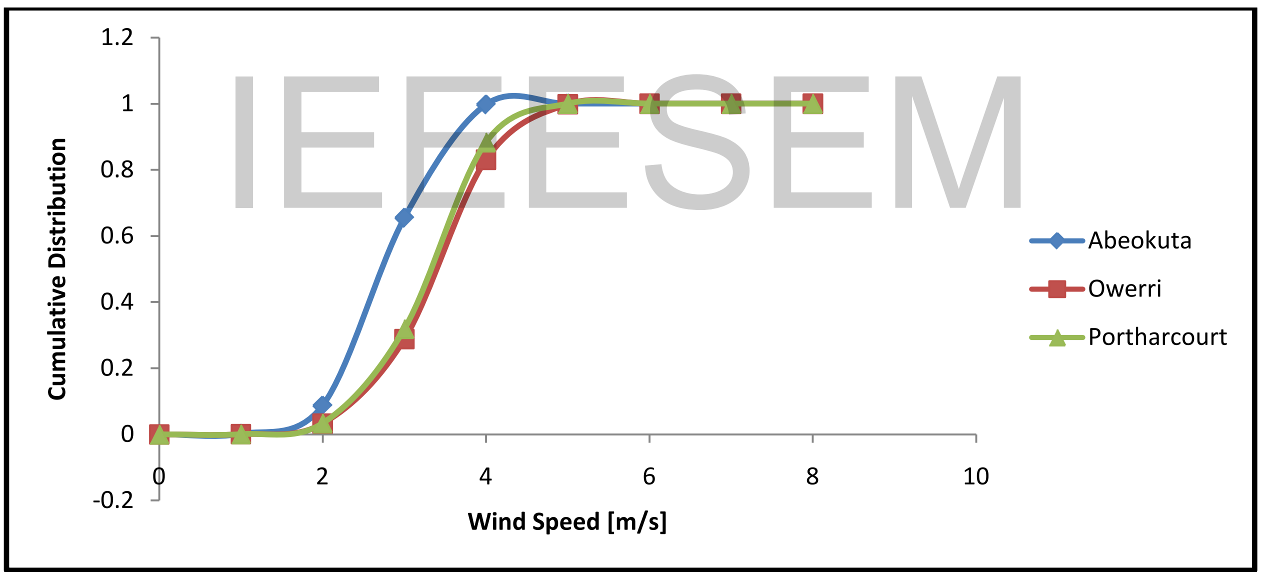

Fig 10: Annual wind cumulative probability distribution for Abeokuta, Owerri and Portharcourt.

The monthly variation of mean wind speed at the six study locations is shown in Fig. 1. The Northern locations experienced more instability in variation than their Southern counterparts. The maximum in Sokoto was 4.74m/s in May and a minimum of 3.66m/s in September; Bauchi had a maximum of 6.38m/s and a minimum of 3.21m/s; and Lokoja had 7.0 m/s in March and 3.65m/s in November, as maximum and minimum speeds, whereas Abeokuta recorded a maximum wind speed of 3.47m/s in February and a minimum of 1.86m/s in November; Owerri had a maximum wind speed of 3.64m/s in March and a minimum of 2.67m/s in November, and Portharcourt had a maximum of 4.28m/s in March and a minimum of 2.89m/s in November. Therefore, throughout the year, the mean wind speed of Sokoto, Bacuchi, Lokoja exceeded that of Abeokuta, Owerri and Portharcourt, with Lokoja being the highest.

The studied locations' wind speed characteristics, namely, most probable wind speed $V_{F,}$ maximum energy wind speed V_E, and wind speed parameter (c) are shown in Figs 2, 3, and 4, respectively. The wind characteristics at Sokoto, Bauchi and Lokoja follow the same trend as the mean wind speed as revealed by Fig. 2. Lokoja still maintained maximum wind characteristics, followed by Bacuchi and Sokoto. It had 7.89m/s as wind speed carrying maximum energy, around March, Bauchi had 7.01m/s in May, and Sokoto had 4.93m/s in January and December. From Fig. 3, Owerri recorded the highest maximum energy wind speed, 5.53m/s in October, followed by Portharcourt, 4.65m/s in March and Abeokuta had least, 3.78 in February. Apart from the one off occurrence of offshoot experienced in Owerri, the Southern locations experience more stable but lower wind characteristics than their Northern counterparts. Fig. 4 shows that the Weibull scale factor varies a little above the mean wind speed for all the locations. Lokoja had a scale factor of 7.57m/s in March, Bauchi had 6.78m/s in May while Sokoto recorded maximum scale factor of 4.88m/s in January and December. The Weibull scale factor follows same trend as maximum energy wind speed, as they occurred at the same time.

The changes that occur in the mean wind power density and wind energy density with the months of the year for all the locations are represented in figures 5 and 6, respectively. The maximum power density was observed in Sokoto around June to be 72.89W/m^2, in Bauchi around May as 169.28W/m^2, and in Lokoja around March as 235.31W/m^2, as shown in Fig.5.

Abeokuta had a maximum mean wind power density of 26.88W/m^2 in February, Owerri had 33.94W/m^2 in April, and Portharcourt had 50.26W/m^2 in March. For Sokoto, Bauchi and Lokoja, the mean wind power density falls into class 1 of Pacific Northwest Laboratory Classification Scheme throughout the year. However, in few instances such as is seen in April and June, at Bauchi location, the mean wind power density fell into class 2 whereas it fell into class 3 in May. Moreso, in Lokoja, it fell into class 2 in July and into class 4 in March and April. Table 1 reveals that the annual mean values fall into category 1 classification for the studied locations. For Southern locations, the maximum values and annual mean values all fell within classification 1. The wind energy density as shown in Fig. 6 follow same trend with Sokoto having a maximum of 48.23kWh/m^2 both in January and December, Bauchi 125.94kWh/m^2 in May and Lokoja 175.07kWh/m^2 in March, while Abeokuta had 19.35kWh/m^2 in March, Owerri had 24.43kWh/m^2 in April and Portharcourt had 37.39kWh/m^2 in March.

The annual wind probability distribution for Sokoto, Bauchi and Lokoja is shown in Fig. 7, while that of Abeokuta, Owerri, and Portharcourt is shown in Fig. 8. The peaks of the frequencies of the density functions of Figs 7 and 8 for all the locations are skewed towards the maximum mean wind speeds. Hence, the expected most frequent wind speed in Sokoto, Bauchi and Lokoja are 4.0, 4.6 and 4.8m/s, respectively, while that in Abeokuta, Owerri and Portharcourt are 3.0, 3.4 and 3.2m/s, respectively. Figs 9 and 10 represent annual cumulative distribution of wind speed for Sokoto, Bauchi and Lokoja, and Abeokuta, Owerri and Portharcourt respectively. This is an indication of speed intervals where the wind speed is most occurring. Among all the studied locations, Lokoja maintained the highest annual average wind speed, wind characteristics, as well as annual power and energy densities. The wind speed that has the highest energy V_E, is a prime parameter in wind turbine sizing and should very near the proposed wind system installation design speed.

4 Conclusions

The characteristics and energy potential of wind resource in six chosen locations, namely, Sokoto, Bauchi, Lokoja, Abeokuta, Owerri and Portharcourt, representing the geographical spread of Nigeria has been investigated using the Weibull probability function. Nigeria is rich with enormous wind resources. The wind resources in the Northern locations fall into classes 2, 3 and 4 schemes and considered suitable for medium scale electricity generation and water pumping. Lokoja seems more promising for wind turbine installations from all the investigated locations. Although, the wind resource in Southern locations fall mostly into class 1 category, which is not adequate for harnessing wind energy on a large scale for power generation, it seems favourable for distributed installations for such activities as water pumping and small household energy needs.

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