An Assessment of Wind Power Density at Selected Heights in Maiduguri, Borno State, Nigeria

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Abstract: ***The focus of this study is to assess the power density in the wind at some selected turbine hub heights to describe the potential for wind power generation in Maiduguri. The power law equation was used to extrapolate the wind speeds at the chosen turbine hub heights of 50 m, 70 m, 90 m and 120 m. The extrapolated wind speeds were employed to estimate the expected monthly wind power densities based on the Weibull distribution. The results show that (i) over 75% of the wind speeds extrapolated in all the months at the selected heights satisfy the cut-in wind speed requirement of 3.5 m/s for most wind power turbines; (ii) wind power density increases with the cube of the scale parameter value of the Weibull distribution; (iii) wind power densities are high between March and July in the range of 427.02 – 735.08 W/m^2, with the peak occurring in June and (iv) the highest power density occurs in June while the lowest power density occurs in October.***

Keywords: cut-in wind speed, extrapolation, wind power density, wind shear exponent, power law, estimation, Weibull distribution

1. Introduction

The use of fossil fuels have raised growing concerns across the globe; partly because of its fast depletion in the midst of high energy demand due to human population upsurge, and partly because of the greater health and environmental impact of the by-products of fossil fuel consumption. Each megawatt of electricity generated using fossil fuels adds around one-half ton of GHG (greenhouse gas), CO_2 equivalent, into the atmosphere [1]. Other gases emitted as by-products of fossil fuel use include CH_4, SO_2, NH_3 and so on. These substances are responsible for global warming, respiratory and cardiovascular diseases, urban smog, acid deposition and visibility degradation.

The concerns rose by the energy crisis and the consciousness on human and environmental health of fossil fuel use have caused growing awareness on the usability of renewable and sustainable energy sources. These energy sources are inexhaustible and have no human and environmental health effects, apart from manufacturing and scrapping process. They include wind, solar, geothermal, ocean thermal, tidal, hydro, bio-energy and so on. Installations in energy generation using these sources have been on the increase globally. Wind energy in particular is targeted to play a major role in realizing the dream of meeting at least 20% of the global energy demand by renewable sources by 2020 [2].

Africa cannot afford to be left behind in the global hunt for renewable energy because it suffers largely from the effects of global warming and the proliferation of diseases such as Ebola, Lassa fever, respiratory and cardiovascular diseases and so on. The continent is also in short supply of electricity to meet its growing energy demand. One major advantage of energy generation through renewable sources is that they can easily be deployed at the point of generation. These imply that they are a viable means for rural electrification and water pumping for irrigation purposes. Thus, Nigeria can take due advantage of its enormous wind power potentials to mitigate its energy problems. In this study, the focus is to evaluate the energy potential in the wind at some selected hub heights in Maiduguri, Borno State, Nigeria.

2. The Problem

Wind velocity varies significantly with height above ground due to surface roughness, i.e. friction resistance offered by the earth surface. For an appropriate siting of wind turbine, estimation of wind resource and turbine performance at the given site, the first factor to consider is the variation of wind velocity with hub height. Thus, the initial steps in planning and development of a wind farm project consist in assessing the wind energy potential at the candidate site, as well as understanding how a wind turbine will respond to wind fluctuations. Most meteorological stations, especially in Nigeria, have wind measuring towers that are not taller than 10 m above ground, and they are not designed for wind energy applications. Hence, it is expedient to extrapolate wind speeds at turbine hub height for appropriate power estimation and wind energy development.

3. Literature Review

There is a growing literature on the use of wind resources for power generation around the globe. Several studies on the viability of wind resources for power generation in Nigeria have shown that the Northern part of the country have higher potentials compared to the other regions, as presented in [3], [4], [5], for example.

More close studies involving the analysis of wind regimes and performance of wind turbines at varying turbine hub heights are found in [6], [1], [2], [7], [8] and [9]. In [10] specifically, several methods of extrapolation of wind speeds at turbine hub height are studied, including the use of the power law. A study in Africa that pertains to wind speed assessment at turbine hub height is found in [11] and [12].

4. Methodology

4.1 The Power Law

This is the most widely used method for extrapolating wind speeds at turbine hub heights (see for example [10]). The method relies only on the wind speed at the reference height h_1 (typically the anemometer height of 10 m above ground level) and a shear exponent, τ, that governs the amount of wind shear between the reference height h_1 and the turbine hub height, h_2. The value of the shear exponent varies with atmospheric stability and surface roughness. The power law equation is given by

$$v_2 = v_1 \left({}^{h_2}/_{h_1}\right)^{\tau} \tag{1}$$

where v_2 is the wind speed at turbine hub height, h_2, v_1 is the wind speed at reference height, h_1, and τ is the wind shear exponent.

The empirical value of the shear exponent, τ, used in making Wind Atlas Analysis and Application Program (WAsP) is $\frac{1}{7}$ (see for example [13]; [14]). But it has been shown in [15], using anemometer mounted at higher hub height, that the shear exponent, τ, is significantly greater than $\frac{1}{7}$. In addition, wind shear exponent is a dynamic value that varies according to a large number of factors, including time of day, season, atmospheric stability and regional topography. Many researchers do not have the resources to conduct field investigations, instead they depend upon the available 10 m meteorological height data and the wind shear exponent value estimated is assumed an annual constant value. Thus, using the 10 m meteorological height h_1 as a reference height and its corresponding wind speeds, v_1, the wind shear exponent is estimated [11] by

$$\hat{\tau} = \frac{0.37 - 0.0088 \ln(v_1)}{1 - 0.0088 \ln\left(\frac{h_1}{10}\right)} \tag{2}$$

The wind shear exponent estimated using equation (2) above is assumed a constant value for the study site and the mean wind speed for the site is employed for v_1.

4.2 Estimation of the Weibull Parameters

The Weibull distribution has a global acceptance for modeling wind speed data (see for example [14], [16], [17], [18], [19], [20]). In [21], it is shown that the Weibull distribution is a good fit for the wind speed data of Maiduguri. The density function is given by

$$f_X(x;\alpha,\beta) = \begin{cases} \beta\alpha^{-\beta}x^{\beta-1}e^{-\left(\frac{x}{\alpha}\right)^{\beta}}, & x > 0,\ \alpha > 0 \text{ and } \beta > 0 \\ 0 & otherwise \end{cases} \tag{3}$$

To estimate the Weibull parameters for the extrapolated wind speeds at the various turbine hub heights, the Newton-Raphson optimization method is employed. Here the objective function is minus the log-likelihood function and is given by

$$obj = -nlog\beta + nlog\alpha - (\beta - 1)\sum_{i=1}^{n} logx_i + n(\beta - 1)log\alpha + \sum_{i=1}^{n}\left(\frac{x_i}{\alpha}\right)^{\beta} \tag{4}$$

The Newton-Raphson iterative solution method given by

$$\hat{B}^{i+1} = \hat{B}^{i} + \varphi \boldsymbol{J}^{-1}(-f),\ \ i = 0, 1, 2, 3, \ldots \tag{5}$$

where $B^i = \begin{bmatrix}\alpha_i \\ \beta_i\end{bmatrix}$, $i = 0$ gives the initial values of α and β, $\boldsymbol{J} = \begin{pmatrix} \frac{\partial f_1}{\partial \alpha} & \frac{\partial f_1}{\partial \beta} \\ \frac{\partial f_2}{\partial \alpha} & \frac{\partial f_2}{\partial \beta} \end{pmatrix}$, $f = \begin{bmatrix} f_1 \\ f_2 \end{bmatrix}$, f_1 and f_2 are the first partial derivatives of the objective function (4) with respect to the parameters α and β, respectively. Values for f and $\boldsymbol{J}$ are obtained using the i^{th} iteration values of the parameters α and β. The constant $\varphi = 0.5$, called the relaxation factor, helps to keep the iterative process on the path of convergence. The iterative process is executed using the R program **Weibull.NM** in [21]. The maximum likelihood estimation is preferred because it satisfies the properties of UMVUEs - efficiency, consistency and asymptotic normality.

4.3 Goodness-of-Fit Test

The Anderson-Darling test statistic is given by

$$A^2 = -\frac{1}{n}\sum_{j=1}^{n}(2j - 1)\left\{log\left(F_o\left(x_{(i)}\right)\right) + log\left(1 - F_o\left(x_{(n-i+1)}\right)\right)\right\} - n \tag{6}$$

where $F_o\left(x_{(.)}\right)$ is the fitted distribution function at the ordered wind speeds.

The test statistic in equation (6) is employed to determine the fitness of the Weibull distribution to the extrapolated wind speed data at the various turbine hub heights. This test statistic is specifically chosen because of its ability to test the goodness-of-fit of a specified continuous distribution without having to compare with the empirical cumulative distribution function (ecdf).

4.4 Air Density and Wind Power Density Estimation

Wind power density depends linearly on air density, which, for simplicity, is assumed to be uncorrelated with wind speed throughout the averaging period. The standard air density value used for wind energy assessment such as in Wind Atlas Analysis and Application Program (WAsP) is $\rho = 1.225 kg/m^3$ [19]; estimated at an assumed air temperature of 15°C (59° F). However, the air temperature of some other places, say for Maiduguri, may be different from 15° C. For such conditions, the air density can be estimated using a formula transformed from the ideal gas law equation [22], and given by

$$\rho = \frac{P \times W \times 10^{-3}}{R \times T} kg/g \tag{7}$$

where P is the atmospheric pressure, $W = 28.97 g.mol^{-1}$ is the molecular weight of air, $R = 8.2056 \times 10^{-5}$ $m^3.atm.K^{-1}mol^{-1}$ is the ideal gas constant, and $T = °C + 273.15\ K$ is the absolute temperature.

The expected monthly wind power density per unit area (in metres) of a site based on the Weibull probability density function and air density is given by

$$P_W = \frac{1}{2}\rho\hat{\alpha}^3\Gamma\left(1 + \frac{3}{\hat{\beta}}\right) \tag{8}$$

where ρ, is the air density as defined above, $\hat{\alpha}$ and $\hat{\beta}$ are the estimated scale parameter (in unit of wind speed) and the dimensionless shape parameter, respectively.

5. Results

5.1 The Wind Speed Data

The wind speed data for Maiduguri used in this study is the monthly average wind speed measured at 10 m above ground level using cup anemometer by the Nigerian Meteorological Agency (NIMET). It is obtained for a period from September 1985 to December 2011. This is presented in [21].

5.2 Extrapolation of Wind Speeds at Selected Heights

In this study, four heights above ground level are considered, namely; 50 m, 70 m, 90 m and 120 m. These heights are chosen to represent the turbine hub heights for industrial wind energy development. In this study the wind shear exponent is estimated separately for each month using equation (2) with $h_1 = 10\,m$ and v_1 is the monthly average of the historical wind speed for the study site. The minimum estimate of 0.3575 was obtained in the month of June and maximum of 0.3629 was obtained in October, with overall average of 0.3600. This estimate is appropriate, considering that the wind speed data were collected at Maiduguri Airport, which falls in the range for large cities with tall buildings [22].

The wind shear exponent value estimated is employed in equation (1) to extrapolate the wind speed for the selected heights above ground level for each month using the data. Some descriptive statistics of the extrapolated wind speed are presented in Table 1 below

Table 1: Descriptive Statistics of Wind Speed at the selected Heights

		Month											
Height		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
50 m	Min	1.61	2.25	2.94	3.10	3.03	2.99	2.31	1.61	1.90	1.61	1.50	1.52
	P_{10}	2.61	3.20	3.76	4.52	4.12	4.28	3.64	3.19	2.61	2.13	2.42	2.22
	Q_1	4.07	4.32	5.12	5.18	5.70	6.24	5.40	4.14	3.60	3.25	3.21	3.35
	Max	8.08	8.82	9.86	9.85	9.69	11.09	11.11	7.70	8.81	7.14	9.13	7.24
	$\bar{X}$	5.03	5.57	6.14	6.31	6.60	7.35	6.56	5.13	4.56	4.00	4.48	4.34
	$se(\bar{X})$	.0639	.0722	.0696	.0612	.0675	.0863	.0866	.0621	.0585	.0505	.0649	.0586
70 m	Min	1.82	2.54	3.31	3.50	3.42	3.37	2.61	1.82	2.14	1.82	1.70	1.72
	P_{10}	2.95	3.62	4.24	5.10	4.65	4.82	4.11	3.60	2.95	2.42	2.73	2.51
	Q_1	4.59	4.88	5.77	5.84	6.43	7.04	6.10	4.68	4.06	3.68	3.62	3.78
	Max	9.12	9.95	11.12	11.12	10.93	12.51	12.54	8.70	9.95	8.06	10.31	8.17
	$\bar{X}$	5.68	6.29	6.92	7.12	7.45	8.29	7.41	5.80	5.15	4.52	5.05	4.91
	$se(\bar{X})$	.0722	.0815	.0786	.0690	.0762	.0974	.0977	.0701	.0661	.0570	.0733	.0662
90 m	Min	1.99	2.78	3.63	3.83	3.74	3.69	2.86	1.99	2.35	2.00	1.86	1.88
	P_{10}	3.23	3.96	4.64	5.58	5.09	5.28	4.50	3.94	3.23	2.65	2.99	2.74
	Q_1	5.03	5.34	6.32	6.39	7.04	7.70	6.67	5.12	4.45	4.03	3.96	4.14
	Max	9.99	10.90	12.17	12.17	11.96	13.69	13.72	9.52	10.89	8.84	11.30	8.95
	$\bar{X}$	6.22	6.89	7.59	7.79	8.15	9.07	8.10	6.35	5.65	4.96	5.54	5.37
	$se(\bar{X})$	.0790	.0892	.0860	.0755	.0833	.1065	.1069	.0768	.0724	.0625	.0803	.0726
120 m	Min	2.21	3.08	4.03	4.24	4.14	4.08	3.16	2.21	2.60	2.22	2.06	2.09
	P_{10}	3.58	4.39	5.15	6.18	5.64	5.85	4.98	4.37	3.58	2.94	3.32	3.05
	Q_1	5.58	5.92	7.01	7.09	7.80	8.54	7.40	5.68	4.94	4.47	4.40	4.60
	Max	11.08	12.08	13.50	13.49	13.25	15.17	16.21	10.56	12.09	9.81	12.54	9.94
	$\bar{X}$	6.90	7.63	8.41	8.64	9.03	10.06	8.99	7.04	6.26	5.50	6.14	5.97
	$se(\bar{X})$	.0877	.0990	.0950	.0838	.0924	.1181	.1185	.0852	.0803	.0693	.0891	.0805

An observation of Table 1 above shows that the minimum extrapolated wind speed at 50 m above ground level is not sufficient for generating power with a wind turbine that requires a cut-in speed of 3.5 m/s in all the months of the year. The months of March to July can provide the minimum requirement in 90% of the time, and for 75% of the time, only the months of October, November and December are not feasible. A further observation shows that from the height of 70 m upwards, the winds are capable of providing power 75% of the time with a turbine requiring a cut-in speed of 3.5 m/s in all the months of the year. Finally, even at the height of 120 m, it's not in all the months that the wind is feasible for providing power with a wind turbine requiring a cut-in wind speed of 3.5 m/s in 90% of the time and above.

5.3 Estimation of Weibull Parameters

The Weibull parameter estimates of the extrapolated wind speeds, with their standard errors, at the selected heights above ground level are presented in Table 2 below

Table 2: Weibull Parameter Estimates at selected Heights above ground level

	Turbine Hub Height							
	50 m		70 m		90 m		120 m	
Month	$\hat{\alpha}\,(se)$	$\hat{\beta}\,(se)$	$\hat{\alpha}\,(se)$	$\hat{\beta}\,(se)$	$\hat{\alpha}\,(se)$	$\hat{\beta}\,(se)$	$\hat{\alpha}\,(se)$	$\hat{\beta}\,(se)$
January	5.60 (.456)	3.56 (.805)	6.32 (.483)	3.56 (.754)	6.92 (.505)	3.56 (.721)	7.68 (.533)	3.56 (.686)
February	6.22 (.482)	3.44 (.704)	7.02 (.513)	3.44 (.663)	7.68 (.539)	3.44 (.637)	8.52 (.572)	3.44 (.610)
March	6.80 (.500)	3.92 (.849)	7.67 (.530)	3.92 (.798)	8.40 (.556)	3.92 (.764)	9.31 (.588)	3.92 (.729)

April	6.91 (.500)	4.45 (1.04)	7.80 (.529)	4.45 (.973)	8.54 (.554)	4.45 (.930)	9.46 (.584)	4.45 (.884)
May	7.24 (.524)	4.54 (1.15)	8.17 (.551)	4.54 (1.07)	8.94 (.573)	4.54 (1.02)	9.91 (.602)	4.54 (.964)
June	8.15 (.549)	3.83 (.758)	9.19 (.586)	3.83 (.717)	10.05(.616)	3.83 (.690)	11.14(.656)	3.83 (.662)
July	7.32 (.524)	3.31 (.588)	8.26 (.564)	3.31 (.561)	9.04 (.597)	3.31 (.543)	10.02(.641)	3.31 (.526)
August	5.69 (.462)	3.75 (.886)	6.43 (.487)	3.75 (.828)	7.04 (.509)	3.75 (.789)	7.81 (.536)	3.75 (.749)
September	5.10 (.418)	3.17 (.587)	5.76 (.448)	3.17 (.557)	6.30 (.473)	3.17 (.536)	7.00 (.504)	3.17 (.515)
October	4.47 (.394)	3.28 (.693)	5.05 (.419)	3.28 (.652)	5.53 (.439)	3.28 (.624)	6.14 (.465)	3.28 (.596)
November	5.03 (.424)	2.81 (.481)	5.68 (.457)	2.81 (.459)	6.22 (.484)	2.81 (.444)	6.91 (.519)	2.81 (.429)
December	4.87 (.416)	3.10 (.614)	5.50 (.443)	3.10 (.580)	6.02 (.466)	3.10 (.557)	6.68 (.495)	3.10 (.533)

The Weibull parameter estimates in Table 2 show that the scale parameter increases with height above ground level. This is because the scale parameter is closely related to the wind speed which also increases with height. However, the shape parameter, which is a dimensionless quantity, is seen to remain unchanged as the height above ground level increases from 50 m to 120 m. This could result from the constant shear exponent used for all the selected heights.

5.4 Goodness of Fit Test

The Anderson-Darling goodness-of-fit test results are presented in Table 3 below. The test hypothesis is that the wind speeds extrapolated at the selected heights above ground level can be described using the Weibull distribution

Table 3: Anderson-Darling Goodness-of-Fit Test Results for the selected Heights

Month	Turbine Hub Heights				Critical Value
	50 m	70 m	90 m	120 m	
January	.405	.405	.405	.405	.740
February	.262	.262	.262	.262	.745
March	.174	.174	.174	.174	.745
April	.147	.147	.147	.147	.745
May	.248	.248	.248	.248	.745
June	.174	.174	.174	.174	.740
July	.210	.210	.210	.210	.745
August	.212	.212	.212	.212	.745
September	.248	.248	.248	.248	.745
October	.252	.252	.252	.252	.745
November	.300	.300	.300	.300	.745
December	.250	.250	.250	.250	.745

The goodness-of-fit tests results in Table 3 show that the Weibull distribution is a good fit for the extrapolated wind speed at all the selected heights at the study area. The test statistic computed for all the months and heights above ground level are less than the corresponding critical values, implying the test hypothesis is not to be rejected.

5.5 Air Density and Wind Power Density

Air density decreases with increased temperature and decreased atmospheric pressure [22]. And the standard air density of 1.225 kg/m^3 (estimated at assumed temperature of 15 °C and atmospheric pressure of 1 atm) is not appropriate for power estimation in Maiduguri, whose historical average air temperature is in the range of 21°C - 42°C and average atmospheric pressure in the range of 987.82 – 1017.8 *hp*a (hector-pascals). Using the conversion rate of 1 atm = 1013.25 *hp*a, the atmospheric pressure is estimated for Maiduguri as 0.9897 atm and the historical average temperature of 31.5°C for and the air density is estimated using equation (7) as 1.1471 kg/m^3. This is employed in equation (8) along with the parameter values of Table 2 to estimate the power density in the wind in Watts per square metre, and the result is presented in Table 4 below.

Table 4: Wind Power Density (Watts/m^2) at Turbine Hub Heights and Anemometer Height

Month	Turbine Hub Heights			
	50 m	70 m	90 m	120 m
January	95.02	136.59	179.30	245.11
February	131.47	189.00	247.47	337.88
March	166.39	238.77	313.64	427.02
April	171.07	246.05	322.93	438.95
May	196.29	282.06	369.57	503.38
June	287.84	412.69	539.73	735.08
July	216.85	311.58	408.44	556.20
August	98.41	142.01	186.39	254.48
September	74.45	107.25	140.33	192.50
October	49.53	71.42	93.78	128.36
November	75.22	108.31	142.23	195.01
December	65.37	94.16	123.48	168.70

The estimates of the power density in the wind at the selected heights above ground level in Table 4 are presented in Figure 1 below.

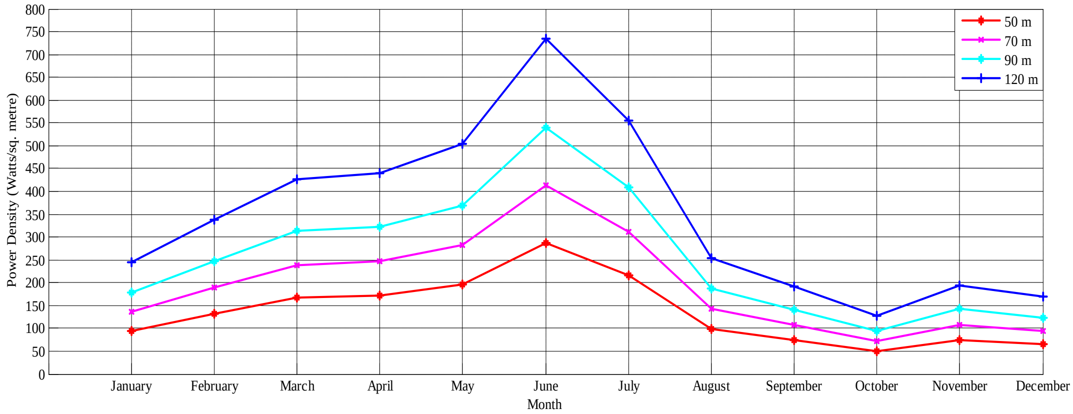

Figure 1: Wind Power Density per Square Metre at the selected Turbine Hub Heights

From Figure 1 the power density in the wind is seen to increase as the height above ground level increases in all the months of the year. This shows a relationship between power density and the scale parameter which is in the dimension of the wind speed, depicted in equation (8). The parameter estimates of Table 2 show increase in the scale parameter with height above ground level. The power density estimates presented in Figure 1 also shows a relationship between power density and the height above ground level. This further buttresses the relationship between the scale parameter and power density, and it is illustrated in Figure 2 below.

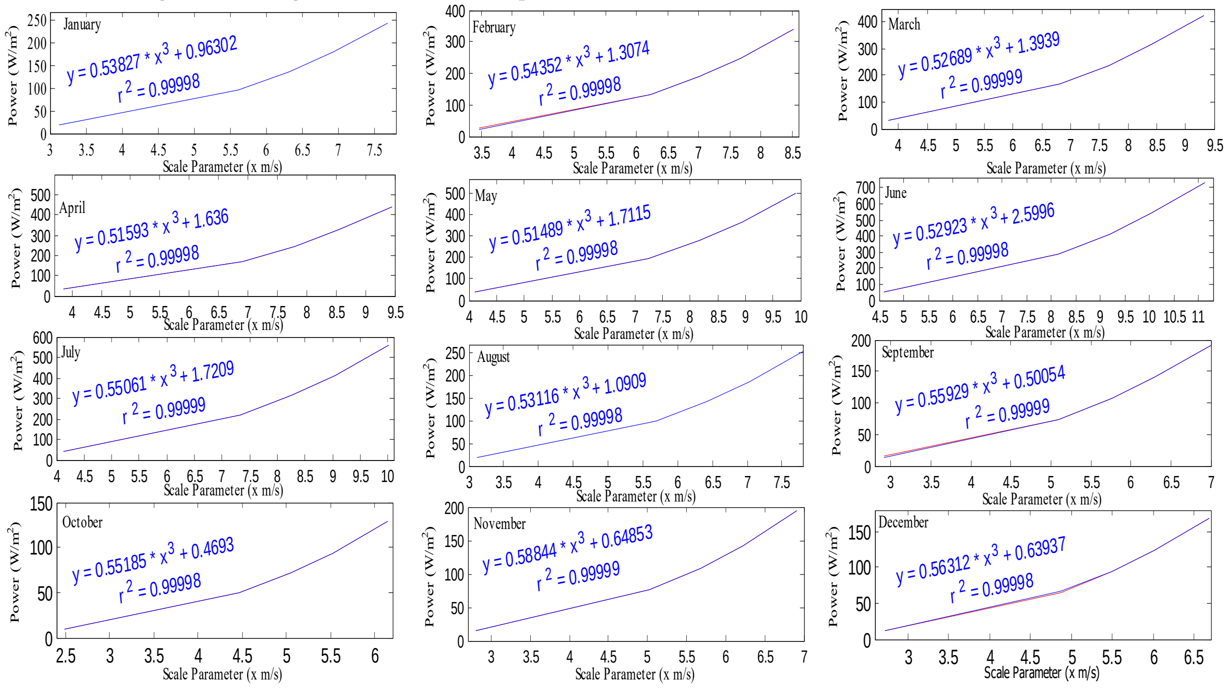

Figure 2: Power Density as function of Scale parameter for the various months

The cube of the scale parameter of the Weibull distribution is seen in equation (8) to be a key determinant of the power density in the wind. This implies that power density increases with the cube of wind speed. In Figure 2, it is clear that the power density in the wind increases with the cube of the value of the scale parameter. This dependence of the wind power density on the scale parameter at the study site is significantly explained (over 99.9%) in all the months of the year.

6. Discussion

From Table 1, the minimum of the extrapolated wind speeds is not sufficient to meet up the cut-in speed of 3.5 m/s for most industrial wind turbines for the heights of 50 m and 70 m above ground level. However, 90% of the wind speeds extrapolated at height of 50 m satisfy the cut-in speed in the months of March to July while those at 70 m above ground level meet the cut-in requirement in most of the months of the year except September through January. Over 75% of the extrapolated wind speeds meet the cut-in requirement at almost all the selected heights in all the months except the height of 50 m at which deficiency is found in the months of October through December. The minimum extrapolated wind speeds meet the cut-in wind speed requirement in the months of Match through June at 90 m and 120 m above ground level. Over 90% of the winds are sufficient from February through August at 90 m above ground level and January to September at 120 m above ground level. At 90 m above ground level and higher, it could be observed that more than 75% of the extrapolated winds are sufficient for the cut-in wind speed. In addition, all the months of the year have wind speed within 2 times the standard error of the mean sufficient to satisfy the cut-in wind speed of 3.5 m/s at 50 m above ground level and higher.

From Table 2, it is seen that the values of the scale parameter estimates of the Weibull distribution increases proportionally as the height above ground level increases. The shape parameter remains the same for all the selected heights. This could result from using the same wind speed at the reference (anemometer) height of 10 m and mean shear exponent to extrapolate the wind speed at the selected heights.

The Anderson-Darling goodness-of-fit test results presented in Table 3 show that the Weibull distribution is a good fit to the extrapolated wind speed data of Maiduguri. The computed values of the test based on equation (6) gave values that are less than the critical values of at least 0.740, which imply that the null hypothesis of no significant difference between the unknown values of the parameters of the Weibull density and their estimates given in Table 2 is not to be rejected. This further implies that the difference between the unknown values of the parameters of the Weibull density and their estimates at all the selected heights above ground level is negligible. The test results agree with the findings in [21], that the Weibull distribution is a good fit to the wind speed data of Maiduguri; and, in addition, show that the fitness of a set of wind data at the reference anemometer height is applicable to all heights at which wind speed is extrapolated.

The main focus of this study is to assess the wind power density based on the extrapolated wind speeds at the selected heights above ground level. From Table 4, the power density is higher in the months of March through July, within range of 166.39 – 287.85 W/m^2, 238.77 – 412.69 W/m^2, 313.64 – 539.73 W/m^2 and 427.02 – 735.08 W/m^2 at heights of 50 m, 70 m, 90 m and 120 m above ground level, respectively. The peak of the power density is in June as the upper limit of the range above and represented in Figure 1. The increase in power density from January to its peak in June, as seen in Figure 1, is because wind speeds are a function of sun intensity, and the study area is characterized by increasing sun intensity in these months. This period is also characterized by low power generation from the national hydropower stations and consequently, a drop in the quantum of power distributed on the national grid. Thus, the high rate of intermittence in hydropower supply due to drastic drop in water levels from the hydropower dams during this period can be augmented if a reasonable investment is made to harness the wind potential for power generation at the study area.

The power density in the wind is a function of the cube of the scale parameter of the Weibull distribution (in dimension of wind speed) as shown in equation (8). And from Table 3 the scale parameter varies with height while the shape parameter is constant. This means that the power estimate in Table 4 is a function of the cube of the scale parameter while the shape parameter remains constant based on Table 3. This further buttresses the relationship between the power density in the wind and the scale parameter of the Weibull distribution in equation (8), and is represented in Figure 2. From the figure, it could be observed that the relationship between these quantities is significantly fitted with over 99.9% of the total variation in the power density explained by the cube of the scale parameter alone in all the months of the year.

7. Conclusion

The extrapolated wind speeds at the selected heights of 50 m, 70 m, 90 m and 120 m above ground level were seen to be viable for power generation at the study site. The true mean wind speeds are within 2 times the standard error of the mean of the extrapolated wind speed and is sufficient to satisfy the cut-in speed requirement of most industrial wind turbines. In addition, 75% of the wind speeds extrapolated in all the months at the selected heights satisfy this cut-in requirement. Wind power density was shown to increase with increase in height and cube of the scale parameter; the latter being in the dimension of the wind speed. The power density in the wind at 120 m turbine hub height is higher from March through July in the range of 427.02 – 735.08 W/m^2; and with the peak occurring in June. This could be the result of increase sun intensity and the approaching rainy season. It could be seen that there is reasonable wind power potential in the study area for power generation. Low wind power density are seen from August and decrease through to January, with the lowest in October at 128.36 W/m^2 at 120 m above ground level.

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