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Determination of the optimal location for maximizing wind energy generation in Northern Nigeria

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ABSTRACT

The global energy consumption has surged from the minimal requirements of primitive societies to today's extensive needs, which are being met primarily by fossil fuels. However, the environmental impact of these fuels, emitting greenhouse gases and contributing to global warming, prompts a reevaluation. Renewable energy is becoming an essential alternative energy source, and wind energy is one of the viable options. This study investigates the viability of wind energy in Northern Nigeria as a safer alternative to fossil fuel-based energy generation. Comprehensive wind data of two decades was obtained for six stations across three geographical zones in Northern Nigeria, detailing hourly readings at 10-meter and 80-meter heights. The study determined monthly and yearly wind speeds, as well as wind power density (WPD) at 10 meters per station. Results unveiled the regional distribution of mean wind speed, ranging from the highest in Jos (9.9 m/s) to the lowest in Yola (1.86 m/s). Employing diverse wind turbine models, including Acciona 70/1500 class I, GE 1.6-100, and Samsung 2.5/90, the study evaluated the Annual Energy Output and Net Capacity Factor. Notably, Jos exhibited the highest WPD (1402 W/m²), contrasting with Yola's lowest (15.9 W/m²) at 80 meters. The findings indicate that Sokoto, Kano and Jos possess enough potential capable of generating electricity for integration into the national grid, while the remaining stations hold sufficient wind energy potential suitable for powering irrigation devices and other agricultural activities. It is recommended that the areas with high potential for wind energy should be harnessed into the national grid by the Government by providing funds to actualise this project on a large scale for the nation.

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INTRODUCTION

The world's energy consumption has significantly increased from the era of prehistoric man, who used relatively little energy each day, to the present era, when energy is of great importance. As the need for energy increased, the demand was met through the use of fossil fuels like coal, oil and natural gas. It is known that these fossil fuels are producers of greenhouse gases that pollute the atmosphere by contributing to the greenhouse effect, which is causing global warming. Numerous nations globally have acknowledged that prevailing energy patterns are not viable and that a more optimal equilibrium must be achieved between energy security, economic advancement, and environmental preservation (Xuewei *et al.*, 2020). Recognizing the unsustainability of current energy trends, many countries as advocate to achieve a more optimal balance between energy stability, economic growth, and safeguarding the environment.

In the context of Nigeria, energy development has been challenging, marked by frequent power interruptions, impeding economic conditions and prompting reliance on gasoline generators with notable contributions to carbon emissions. To address this, the adoption of renewable energy sources, particularly wind energy, emerges as a viable solution due to their vast, largely untapped, and sustainable capacity (Bouzeria *et al.*, 2018). Wind energy stands out among renewables for its cleanliness and ability to generate substantial electric power. Despite wind energy's historical underrepresentation in Nigeria's energy mix, recent initiatives like the Renewable Energy Master Plan (REMP) signify a governmental commitment to diversify and increase renewable energy capacity. Wind, though minimally used currently, holds promise for widespread adoption. The historical use of windmills in the 1960s for water pumping in regions like Sokoto and Garo demonstrates a precedent for wind energy utilization. However, with the drop in fossil fuel prices, interest waned, leading to infrastructure deterioration. Presently, the resurgence of interest in wind energy is gaining traction, attracting governmental attention. Although policies are still in the early stages, Nigeria's potential for wind energy is substantiated by studies revealing favourable wind speeds and power densities in areas like Jos, Kano, and the Northeast (Hedayati-Mehdiabadi *et al.*, 2017). Notably, Jos emerges as an ideal location for wind turbine installation, presenting potential energy densities that could meet electricity or water pumping needs at costs competitive with other energy sources. To ascertain the possibility of wind energy being used as a source of electricity in Nigeria, it is imperative to thoroughly analyse the available wind data for energy conversion.

The country's energy limitations have been a concerning issue for almost half a century. Realizing the need for sufficient and maintainable energy provisions for power generation has caused the intervention of the Government through initiatives to check for potential residents in renewable resources to generate power (Hedayati-Mehdiabadi *et al.*, 2017; Tsioumas *et al.*, 2016; Ghazal *et al.*, 2021). Presently, the Government at the federal level is devoted to securing a permanent answer to this dilemma by adopting an initiative referred to as the Renewable Energy Master Plan (REMP) whose target would be to increase installing what is presently 5000 MW capacity in a generation to 16,000MW by 2015 by exploring resources in renewable energy (Iloeje, 2001). To be able to achieve this objective, the exploration of energy provided by wind is an essential element within this scheme. Wind energy as a share of the energy consumed within the nation has been relatively minuscule. Currently, natural gas, electricity by water, wood/charcoal, and gasoline make up 5.2, 3.1, 50.5 and 41.3% share of the nation's energy consumption index, respectively. This means that at this time, the use of renewables energy in Nigeria is covered mostly by hydroelectricity and wood fuel use. A developing nation like Nigeria does not accord exploring wind energy the attention it deserves, with wind power plants absent from the national grid, instead, there exists stand-alone wind power plants built on a reduced scale.

Windmills were initially employed in Nigeria during the mid-1960s in the northern areas of Sokoto and Garo. More than 20 residences and educational institutions utilised windmills for water pumping purposes. In the subsequent decades, the cost of fossil fuels decreased, making wind power less attractive due to its relatively inexpensive nature. The investment in windmills was discontinued, leading to the deterioration of the infrastructure and rendering it outdated.Using wind as a resource for generating power in Nigeria is beginning to gain popularity and attracting the attention of the Government. However, the generating policy in the country is still at the stage of

inception, and working wind energy resources for power generating power are severely lacking in physical terms in the nation; what resides is forensic evidence indicating the previous use of wind for pumping water.
According to a research conducted by Owoeye *et al.*, in 2017, certain coastal districts have an annual average wind speed of 2.3-3.4 m/s at a height of 10 m, while places with high land and semi-arid conditions have an average wind speed of roughly 3.0-3.9 m/s. The study also demonstrated that the wind turbine has the capacity to produce an average power of up to 50 W/m^2 from wind in a month.

Similarly, after investigating the wind potential of Jos by (Awogbemi et al., 2015), it was found that the highest power intensity, which could be taken from the wind in the area was 14.23 W/m2. The quantifiable energy density accessible in the wind has also been determined to be 1126 kWh/yr. This study implies that Jos is a good location for the installation of wind turbines. They also estimated that places with annual mean wind speeds of 3.5-4.0 m/s or above can supply enough power to deliver electricity or pump water at costs lower than photovoltaic, diesel, or grid extension

The findings presented in (Abisoye *et al.*, 2011) assert that the Northeastern region of Nigeria boasts elevated wind speeds, with a high likelihood of recurrent occurrences, thereby establishing it as a favourable location for the implementation of a wind energy conversion system. Similarly, (Ajayi and Kantende, 2011) reported conclusive results indicating that the wind power density in Kano ranges from 410.8 to 1424.4 W/m^2, underscoring the substantial potential for harnessing wind energy in this particular area.

OBJECTIVES OF THE STUDY

The study aims at determining towns that are suitable for generation energy through the wind turbine in the northern parts of Nigeria. To achieve this, the hourly wind data for two towns, each from the three different zones in the northern part of the country, was obtained; the data spanned over a period of twenty years. The wind data for each of these six locations was then used to determine the power density. The Annual Energy output and net capacity factor were also obtained for each location using different types of wind turbines.

MATERIALS AND METHODS

Data Collection

Understanding the statistical parameters of wind speed is imperative for accurately estimating the energy output of wind energy conversion systems, given the significant temporal and spatial variability of wind, as emphasized in (Kandemir *et al.*, 2021). This analysis holds paramount importance for researchers and investors engaged in renewable energy studies. The foundational element in the development of any power industry, particularly in wind power engineering, is the precise determination of resource potential and identification of zones with optimal values. Given the stochastic nature of energy supply in wind power, comprehensive knowledge of wind characteristics becomes pivotal for project implementation and operation. This paper undertakes a crucial initial step by analysing data from six meteorological stations, strategically positioned across the three regions of northern Nigeria. The geographical coordinates of these stations are detailed in Table 1. Leveraging data spanning two decades (1996 to 2015) from the Nigeria Meteorological Agency, Oshodi, this study delves into the seasonal and monthly variations in average wind speed, the vertical profile of wind speed, and an assessment of wind power potential.

Table 1: Location of the Six towns in the Northern part of Nigeria

Station	Latitude N	Longitude E	Elevation m
SOKOTO	13.02	5.25	350.8
KANO	12.03	8.12	472.5
ABUJA	9.15	7.00	343.1
JOS	9.52	8.45	586.0

YOLA	9.14	12.28	186.1
MAIDUGURI	11.51	13.05	353.8

Data Analysis Techniques

Wind, characterized by the air masses movement across the Earth's surface, holds paramount importance in the realm of renewable energy. Before establishing any wind energy-based system, a meticulous assessment of the wind's energy potential at a specific site is imperative. Understanding the wind speed regime over a defined period in a region becomes instrumental in optimizing the wind energy conversion design systems, ensuring cost-effective energy generation (Awogbemi *et al.*, 2015). Typically recorded through a time-series approach, where wind speed is logged on an hourly basis throughout the day, this study employs the Weibull density function as the standard method for calculating wind load probabilities (Ajayi and Kantende, 2011; Wang *et al.*, 2023; Maegaard, 2009). Despite its versatility and simplicity, a fundamental shortcoming of the Weibull density function is in its inability to effectively calculate the probability associated with zero or very negligible wind velocities (Maegaard, 2009). Nonetheless, the mathematical approach remains suitable for a great range of measured wind data. The Weibull wind velocity probability density function offers a nuanced understanding of the wind profile at the given site, enabling a comprehensive analysis of wind behaviour and is depicted in the equation below (Wang *et al.*, 2023).

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

In the context of the Weibull density function, denoted by f(v), the parameters include the Weibull scale parameter, c, and the dimensionless Weibull shape parameter, k. The scale parameter, c, essentially indicates the windiness of the specific site under examination. In other words, it provides insights into the general wind conditions at the site. On the other hand, the shape parameter, k, is indicative of the peaked-ness or distribution of wind. A higher value of k signifies that the wind speeds are closely clustered around a particular value, indicating a peaked distribution. Conversely, a lower value of k suggests a more spread-out distribution. The average wind speed (v) and the variance (σ) of wind velocity are mathematically represented as (Ghazal *et al.*, 2021).

$$\bar{v} = \frac{1}{n}\sum_{i=1}^{n} v_i \quad (2)$$

$$\sigma^2 = \frac{1}{n-1}\sum_{1=1}^{n}(v_i - \bar{v})^2 \quad (3)$$

Based on the values of mean, *v* and variance σ, these equations may be employed to evaluate the Weibull parameters, *c* and *k (*Awogbemi *et al.*, 2015):

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \quad (4)$$

$$c = \frac{\bar{v}}{\gamma\left(1+\frac{1}{k}\right)} \quad (5)$$

Wind speed variation with height

The wind speed experiences alterations with altitude, necessitating an equation to predict the wind speed at a specific height based on the measured speed at another height. This variation is primarily due to the impact of surface features, with turbulence decreasing as one ascends. Two fundamental laws govern the variation of wind speed with height: the Power Law and the Logarithmic Law (Awogbemi *et al.*, 2015; Abisoye *et al.*, 2011). These laws articulate the relationship between wind speed and altitude, providing crucial insights into how the wind behaves at different heights above the ground. The Power Law and Logarithmic Law play a pivotal role in understanding the vertical profile of wind speed, contributing to comprehensive analyses of wind behaviour in diverse terrains.
Mathematically, The Power law is denoted as:

$$V/V_0 = \left\{\frac{h}{h_0}\right\}^2 \quad (6)$$

The relationship between wind speed (V) at a specific height (h) and the wind speed at a reference height (V_0) is described by the Power Law equation, where α represents the coefficient of the surface roughness. The exponent α is a crucial factor determining how wind speed varies with height and varies across different terrains, ranging from 0.1 on hilltops to over 0.25 in sheltered areas. In the context of this thesis, the analysis of wind speed with height employed a surface roughness coefficient of 0.14, corresponding to a fallow field. This choice of coefficient reflects the specific characteristics of the surface and contributes to a more accurate understanding of the wind profile in the given context. The logarithmic law is given as:

$$\frac{V}{V(10)} = \frac{In\left(\frac{h}{Z_0}\right)}{In\left(\frac{10}{Z_0}\right)} \quad (7)$$

Where *V (10)* is the wind speed at 10 m height and Z_0 *is* the roughness length, while *V* is the wind speed at the required height h.

Wind Power Density

This is the amount of wind power available per unit of area perpendicular to the wind flow, it is used to determine the power obtainable by the turbine blade at a specified wind speed and it is given by equation 8 (Bouzeria *et al.,* 2018; Hedayati-Mehdiabadi *et al.*, 2017):

$$WPD = \frac{1}{2}\rho v^3 \quad (8)$$

Where ρ is the air density (kg/m^3) and *v* wind speed (m/s).

Estimating wind turbine power output

The equation 9 is used to predict the power output using the power curve for the measured wind speed (Hedayati-Mehdiabadi *et al.,* 2017):

$$P = P_0 \frac{\rho}{\rho_0} \quad (9)$$

Where:

P_0 = Power output predicted (kW)
ρ = Actual air density in the current time step (kg/m^3)
ρ_0 = Air density at which the power curve applies (kg/m^3)

Calculating net mean power output

The cumulative power output of the wind turbine during each time step serves as the basis for determining the overall mean power output across various temporal divisions, such as yearly, monthly, or directional segments within the dataset. This collective gross power output lays the foundation for subsequent calculations. The mean net power output is subsequently derived through the application of the following equation:

$$P_{net} = (1 - f_{overall})P_{gross} \quad (10)$$

Where:

P_{gross} = Mean gross power output, before losses (kW)
$f_{overall}$ = Loss factor

Annual energy output (AEP)

The energy output is determined through the multiplication of the turbine's power output by the corresponding duration. Consequently, the annual energy output (AEP) is computed as the product of the mean net power output and the total number of hours in a year. Equation 11 is applied for the precise calculation of the mean annual net energy (Awogbemi *et al.*, 2015).

$$AEP = P_{net} \times 8760 \quad (11)$$

Where:

P_{net} = Mean net power output over the entire data set (kW)
8760 = Number of hours in a non-leap year

Net Capacity Factor (NCF)

NCF compares the turbine's rated output with the mean power output for the various sites. To calculate the NCF the equation 12 is used (Awogbemi *et al.*, 2015):

$$NCF = \frac{P_{net}}{P_{turbine\,rating}} \quad (12)$$

Where;

P_{net} = Net mean power output (kW)
$P_{Turbine}$ = Rated power of the turbine

RESULTS AND DISCUSSION

The analysis of this two-decade wind speed dataset (1996-2015) at a 10-meter height reveals a range of mean wind speeds from 9.9 m/s to 1.86 m/s across the region, with Jos registering the highest and Yola the lowest speeds. Illustrated in Figure 1 are the monthly mean wind speeds (MMWS) for the six stations, showcasing Jos's peak MMWS at 11.2 m/s in December at 10 meters. Generally, the wind speed values for the stations exhibit a decline from June to November, with the highest speeds occurring between April and June. Notably, Jos deviates from this pattern, experiencing its peak in December, possibly attributed to the harmattan haze prevalent during this period in Jos.

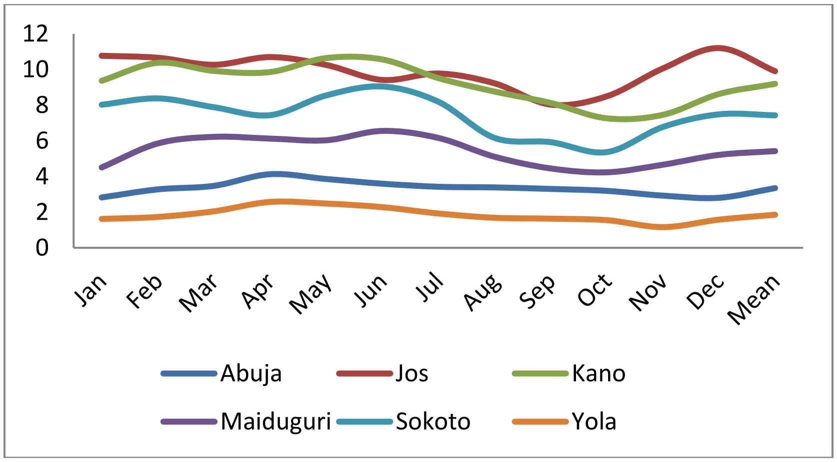

Figure 1: Monthly Mean wind speed at 10 m

Determining the average wind speed in a region represents just the initial phase in comprehending its wind potential. Beyond this, the assessment delves into the critical metric of power density, a significant determinant guiding site selection and immediate classification. Consequently, an in-depth analysis of wind power density across the six selected stations was conducted, with Figure 2 depicting the monthly variation in average wind power density at an 80-meter hub height. A notable trend emerged, where all stations, excluding Jos, showcased a shared inclination towards the highest monthly wind power density during the rainy season (April-June). In contrast, Jos exhibited its peak in December, coinciding with the harmattan haze.

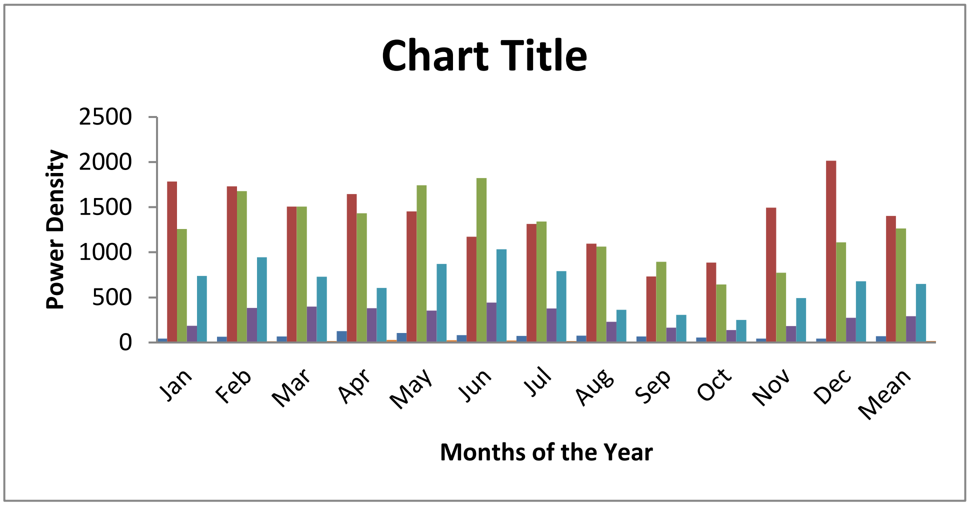

Figure 2: Power Density for the Stations (W/m²)

Analysing the predictability of the statistical Weibull distribution involves a thorough examination of the Weibull-generated data in comparison to the original dataset. In Figures 3a-f, a comprehensive depiction of the comparison between the actual monthly mean data and the estimated monthly mean Weibull frequency distributions of wind speed at 10 m for the six stations is presented. The visual representation clearly illustrates that the Weibull statistical distributions effectively predict the mean wind speed across all six stations in the northern region of Nigeria, thereby showcasing a high level of goodness of fit. Further insights into the Weibull distribution parameters, including shape and scale, are detailed in Table 2, providing a comprehensive overview of the variations in both yearly and monthly means for all stations at 80 m.

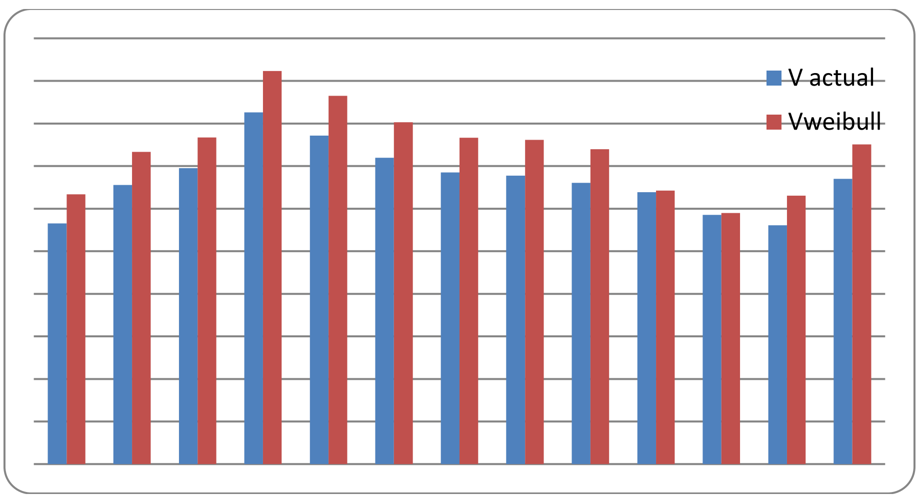

Figure 3: Graph comparing the wind speed data with wind speed from Weibull for Abuja

Table 2: Results of Weibull analyses for the region at 80 m

	Abuja		Jos		Kano		Maiduguri		Sokoto		Yola	
	W_k (m/s)	W_c (m/s)	W_k (m/s)	W_c (m/s)	W_k (m/s)	W_c (m/s)	W_k (m/s)	W_c (m/s)	W_k (m/s)	W_c (m/s)	W_k (m/s)	W_c (m/s)
1996	4.907	2.885	9.626	10.292	3.878	11.49	0.924	4.60	5.326	9.028	3.209	2.358
1997	3.992	2.367	5.163	11.080	5.816	11.671	0.998	5.555	6.309	8.367	3.306	2.003
1998	4.765	2.358	5.584	10.101	4.271	11.425	1.027	5.495	4.312	8.397	2.424	1.823

1999	4.788	2.801	10.000	9.809	4.125	11.725	2.930	6.129	4.701	8.614	2.751	1.770
2000	3.843	3.098	3.276	8.891	3.453	10.976	1.082	5.333	5.482	7.392	1.995	1.616
2001	5.776	4.072	7.156	8.971	3.842	9.622	2.224	5.303	5.245	7.999	3.514	2.298
2002	4.570	4.513	2.707	8.488	1.607	8.293	0.870	4.544	4.859	8.185	3.922	1.950
2003	4.608	4.211	6.258	12.115	1.632	6.735	1.201	5.988	3.968	8.097	2.523	2.171
2004	6.155	4.210	10.000	11.897	1.857	8.840	1.142	7.262	4.808	7.555	4.245	1.942
2005	4.75	4.827	6.864	12.514	3.178	9.093	1.22	6.558	3.08	6.386	2.993	2.041
2006	4.046	3.05	4.074	10.189	3.886	11.198	4.281	4.866	4.571	9.298	0.897	2.219
2007	2.629	2.705	5.032	11.252	6.125	11.47	4.348	5.764	2.178	8.199	0.814	1.909
2008	2.876	2.696	4.735	10.22	4.288	11.172	4.631	5.749	3.19	8.434	2.153	1.946
2009	3.7	3.067	4.432	9.816	4.069	11.443	3.285	5.899	4.404	8.806	2.209	1.883
2010	2.75	3.331	3.161	9.06	3.459	10.763	3.824	5.611	1.613	7.103	1.641	1.78
2011	4.554	4.318	6.476	9.206	4.063	9.458	2.608	5.026	4.349	8.243	0.832	2.18
2012	2.2	4.683	2.612	8.622	4.389	8.68	3.914	4.775	4.224	8.442	0.769	1.86
2013	2.517	4.378	6.135	12.26	6.271	6.942	4.186	6.303	3.53	8.369	2.046	2.317
2014	1.783	4.246	9.767	12.25	6.278	9.127	5.943	7.521	4.134	7.88	0.764	1.876
2015	2.451	4.794	6.601	12.736	5.142	9.158	5.523	6.782	2.858	6.616	5.592	4.138
Jan	2.81	3.168	4.975	11.688	4.305	10.281	0.902	4.469	5.797	8.625	0.745	1.575
Feb	3.132	3.665	5.245	11.563	4.635	11.364	2.764	6.571	3.981	9.236	2.003	1.958
Mar	3.69	3.836	5.649	11.059	4.138	10.864	1.1	6.246	4.914	8.57	0.773	2.016
Apr	3.178	4.616	7.098	11.381	4.651	10.756	0.97	6.11	2.315	7.647	0.973	2.567
May	2.988	4.324	6.844	10.922	5.106	11.522	1.034	6.029	3.028	8.754	0.929	2.476
Jun	3.22	4.013	5.595	10.168	4.046	11.595	1.208	6.588	3.2	9.283	0.745	2.243
Jul	2.957	3.834	3.68	10.273	4.242	10.387	1.184	6.199	5.725	8.812	0.655	1.867
Aug	2.748	3.809	6.018	9.93	3.909	9.654	0.966	5.097	4.154	6.749	0.65	1.645
Sep	2.86	3.698	5.846	8.681	3.489	8.966	0.882	4.42	1.443	5.977	0.682	1.604
Oct	1.143	3.213	4.865	9.238	3.012	7.917	0.862	4.204	1.42	5.451	0.62	1.482
Nov	1.155	2.948	4.876	10.969	2.859	8.354	0.88	4.628	3.979	7.45	7.729	3.474
Dec	2.76	3.151	5.547	12.139	3.243	9.645	1.43	5.36	3.687	8.256	5.173	2.847

Hence, a prudent approach involves aligning the parameters of a wind turbine with the specific wind profile of the site. This encompasses the assessment of the anticipated electrical power output that a particular wind turbine is likely to generate, as highlighted by (Ajayi and Kantende, 2011; Yousefi *et al.*, 2021; Miligan, 2012; Kou *et al.*, 2011). In this investigation, three distinct wind turbines, each characterized by its unique set of parameters, are employed, as detailed in Table 3.

Table 3: Technical Details of Wind Turbine Models Used in the Analysis

	Acciona 70/1500 class 1	GE 1.6-100	Samsung 2.5/90
Rotor Diameter	70 m	100 m	90 m
Cut- In Speed	3.5 m/s	3.5 m/s	3.5 m/s
Cut-out Speed	25 m/s	25 m/s	25 m/s
Rated Output	1500kW	1600 kW	2500 kW
Hub Height	80 m	80 m	80 m

Table 4 presents the monthly mean power output of the Acciona 70/1500 class 1 wind turbine at an 80 m hub height, with the maximum mean monthly output ranging from 1062.57 kW in Jos to 10.7 kW in Yola. The observed variation in the month with the highest mean wind speed and the mean power output can be attributed, in large part, to the prevalence of wind speeds below the cut-in speed during December.

Table 4: Showing the Mean Power Output Using Acciona 70/1500 Class 1

	Abuja	Jos	Kano	Maiduguri	Sokoto	Yola
Jan	45.4	1,154.60	979.6	219.8	834.1	6
Feb	77.7	1,126.20	1,094.70	448.9	873.2	10.9
Mar	83.2	1,120.40	1,039.80	483.3	796.8	12.1
Apr	165.9	1,177.70	1,053.70	452.2	721.6	20.7
May	137.7	1,149.80	1,146.20	430.3	938.9	18.3
Jun	104.1	1,017.90	1,096.70	529.9	1,018.30	14.2
Jul	91.1	1,073.10	998.8	467.5	872.1	9.6
Aug	94.5	1,013.00	887.1	277.4	470.5	7
Sep	81.8	827.5	784.1	191.9	407.8	6.6
Oct	61.9	887.7	633.1	165	327.3	7.6
Nov	45.9	1,059.50	635.2	219.3	589	4.6
Dec	45.9	1,143.40	825.1	319.3	699.2	10.4
Mean	86.2	1,062.57	930.4	349.7	711.5	10.7

The outcomes for the GE 1.6-100 wind turbine at an 80 m hub height are detailed in Table 5, where Jos exhibits the maximum mean monthly output of 1280.20 kW, while Yola records the minimum value of 17.7 kW. The power outputs from the GE 1.6-100 indicate an increase compared to those obtained from the Acciona 70/1500 class 1.

Table 6 delineates the mean power output derived from the Samsung 2.5/90 wind turbine across the six stations. The results illustrate that the mean monthly power output varies from 1815.4 kW in Jos to 34.4 kW in Yola.

Table 5: Showing the Mean Power Output Using GE 1.6-100 Turbine

	Abuja	Jos	Kano	Maiduguri	Sokoto	Yola
Jan	74.9	1,329.90	1,269.40	399.8	1,198.30	11.0
Feb	136.2	1,307.90	1,274.30	730.2	1,138.30	17.1
Mar	143.3	1,318.20	1,263.00	838.1	1,147.80	19.0
Apr	308.7	1,339.10	1,287.50	781.1	1,110.30	31.4
May	256.9	1,334.80	1,333.60	764.5	1,275.30	27.0
Jun	189.4	1,282.20	1,316.10	911.3	1,307.00	21.1
Jul	162.1	1,314.40	1,224.70	819.6	1,205.50	15.9
Aug	170.6	1,260.20	1,203.10	510.4	825.30	12.8
Sep	141.4	1,153.30	1,090.80	346.5	774.80	12.7
Oct	96.7	1,192.50	986.30	295.7	615.60	13.2
Nov	67.2	1,240.70	957.40	405.1	943.10	8.8
Dec	75.3	1,288.30	1,149.20	551.5	1,052.30	17.0
Mean	151.8	1,280.20	1,196.10	611.9	1,049.00	17.2

Table 6: Showing the Mean Power Output Using Samsung 2.5/90

	Abuja	Jos	Kano	Maiduguri	Sokoto	Yola
Jan	112.9	1,966.10	1,690.10	396.1	1,457.90	17.0
Feb	161.9	1,911.30	1,860.00	799.4	1,507.30	33.0
Mar	179.7	1,910.90	1,776.20	850.4	1,388.70	40.3
Apr	313.3	2,000.30	1,803.90	787.4	1,273.60	83.5
May	260.5	1,964.30	1,953.60	748.1	1,646.60	70.9
Jun	204.6	1,750.10	1,868.10	927.5	1,770.70	54.0
Jul	186.4	1,844.70	1,709.20	821.4	1,527.70	29.0
Aug	185.4	1,744.00	1,528.20	487.3	823.00	17.3
Sep	167.3	1,445.50	1,347.90	347.0	701.20	12.7
Oct	144.5	1,535.90	1,087.30	302.7	567.70	21.9
Nov	118.5	1,785.50	1,090.30	392.2	1,034.60	8.8
Dec	108.6	1,926.20	1,424.20	560.4	1,222.30	25.4
Mean	178.5	1,815.40	1,593.70	617.0	1,242.00	34.4

The analysis of the power outputs, the net AEP and NCF obtained for the six stations for the turbines are shown in Tables 7, 8 and 9.

Table 7: Showing the Performance of the Acciona 70/1500 class 1 for the region

	Abuja	Jos	Kano	Maiduguri	Sokoto	Yola
% Of Time At Zero Power	23.23	0.03	0.15	3.18	0.36	76.17
% at Rated Power	0	29.32	24.57	1.22	3.35	0
Net AEP (KWh/yr)	755,000	9,307,835	8,150,265	3,063,164	6,232,852	93,331
NCF (%)	5.75	70.84	62.03	23.31	47.43	0.71

Table 8: Showing the Performance of the GE 1.6-100 for the region

	Abuja	Jos	Kano	Maiduguri	Sokoto	Yola
% Of Time At Zero Power	22.23	0.03	0.15	3.18	0.36	76.17
% at Rated Power	0.03	57.85	43.69	1.77	15.15	0
Net AEP (KWh/yr)	1,329,373	11,214,653	10,477,551	5,360,647	9,189,206	151,013
NCF (%)	9.48	80.01	74.75	38.25	65.56	1.08

Table 9: Showing the Performance of the Samsung 2.5/90 for the region

	Abuja	Jos	Kano	Maiduguri	Sokoto	Yola
% Of Time At Zero Power	22.23	0.03	0.15	3.18	0.36	76.17
% at Rated Power	0	11.33	12.58	0.9	1.45	0
Net AEP (KWh/yr)	1,563,739	15,903,171	13,960,428	5,405,066	10,880,158	301,700
NCF (%)	7.14	72.62	63.75	24.68	49.68	1.38

CONCLUSION AND RECOMMENDATION

The comprehensive analysis of wind data spanning from 1996 to 2015 for six stations across the northern region of Nigeria revealed valuable insights into wind characteristics and wind power density (WPD) using a monthly and yearly data. The study meticulously examined the distribution of mean wind speed, with Jos exhibiting the highest (9.9 m/s) and Yola recording the lowest (1.86 m/s). Additionally, results demonstrated an elevation in wind speed and WPD with height, showcasing the potential for increased energy capture at greater heights. Notably, Jos displayed the highest WPD (1,402 W/m²) at 80 m, while Yola had the lowest (15.9 W/m²). The findings suggested that Sokoto, Kano and Jos hold significant wind energy potential for grid-connected electricity generation, while Maiduguri's potential could be harnessed for agricultural activities. The study recommends the establishment of wind power plants, particularly in Jos, Kano, and Sokoto, integrated with the national grid to leverage their electricity generation capabilities, this will help in solving the shortage of electricity being witnessed in the country, which has led to the closure of many companies. Future research could focus on the use of ducted wind turbine, especially for areas with low wind power density.

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