

Case Report

Feasibility Study for Wind Data Analysis Across Nigeria's 36 States and the Federal Capital Territory, Abuja

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Abstract

In Nigeria, nearly 136.5 million people lack access to clean electricity, representing approximately 61.2% of the total population (According to the National Bureau of Statistics). This study presents key information on wind speed distribution across the country's 36 states, aiming to provide statistical recommendations for wind turbine deployment throughout the federation. Fifteen years of wind data and five years of hourly data from the Nigerian Meteorological Agency (NIMET) were analyzed using the standard deviation method of the Weibull distribution and GIS mapping techniques. The wind energy analysis reveals distinct wind patterns and average speeds across various regions of Nigeria, which influence the feasibility of stand-alone wind energy projects. In the Northwest region, an average wind speed of 4.2 m/s, a shape parameter (k) of 6.77, and a scale parameter (c) of 3.06 indicate moderate wind speeds with a steady distribution, particularly in states such as Sokoto and Gusau. The Northeast region exhibits an average wind speed of 3.5 m/s, with a shape parameter (k) of 5.86 and a scale parameter (c) of 2.88; some locations, like Damaturu, experience wind speeds up to 4 m/s. While the form parameter suggests relatively stable wind patterns, the Southwest region shows comparatively low wind potential, with a shape parameter (k) of 6.46, a scale parameter (c) of 2.25, and an average wind speed of 2.17 m/s. Similarly, the Southeast region has low but stable wind conditions, with an average wind speed of approximately 2.00 m/s and shape and scale parameters of 6.35 and 2.05, respectively. In conclusion, the prospects for wind energy projects appear marginally better in the Northwest and Northeast regions, especially in areas with higher wind speeds. The generally low wind speeds observed in most regions underscore the need for hybrid energy systems that integrate solar and wind power to provide a reliable and sustainable energy source.

Keywords

Hourly Data, Average Windspeed, Geographical Information Systems, Wind Potentials, Wind Energy, States

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1. Introduction

The criterion for a nation's economic advancement is intricately linked to its capacity to generate and distribute power, an indispensable prerequisite for societal growth and national progress [1]. Nigeria is endowed with multiple energy sources, including fossil fuels, nuclear, and renewable options. However, its energy sector remains one of the most inefficient in meeting the needs of its population [2]. Over the years, renewable energy has proven to be inexhaustible, clean, cost-effective, and offers numerous environmental and economic benefits compared to conventional energy sources [3]. Nigeria's electricity grid experienced 541 failures between 2000 and 2021, with the annual number of system collapses reaching alarming levels. This highlights the current conventional transmission system's inability to provide customers with reliable, dependable, and continuous power [4]. Previous studies have focused narrowly on specific states or regions, such as Jos [3] or the Northwest [5]. While these localized efforts are valuable, they lack the comprehensive scope necessary to inform national energy policy. This study addresses this gap by analyzing wind speed data across all 36 Nigerian states and the Federal Capital Territory (FCT), providing a holistic assessment of the country's wind energy potential.

The motivation for this research arises from Nigeria's ongoing energy crisis, characterized by frequent blackouts, excessive reliance on generator sets, and an overstressed transmission grid. The power system network (PSN) currently faces voltage instability [6], despite Nigeria's population being estimated at approximately 227 million and projected to reach 260 million by 2030 [7]. As demand increases, system voltage gradually decreases until a critical threshold is reached. Beyond this point, even a slight increase in demand causes a significant voltage drop [7], ultimately leading to voltage collapse when demand can no longer be met. The adoption of renewable energy could diversify the energy mix, reduce greenhouse gas emissions, and support Nigeria's commitments to global sustainability goals [9], such as the Paris Agreement. By utilizing advanced statistical tools like the Weibull distribution and GIS mapping, this study aims to:

- 1) Quantify the variations in wind speed across Nigeria's geopolitical zones.
- 2) Identify the regions with the highest wind energy potential.
- 3) Provide data-driven recommendations for integrating wind energy into Nigeria's power infrastructure.

Before deciding whether to locate a wind turbine in a particular area, it is essential to assess the wind characteristics of that location [8]. Unlike previous studies, which often relied on limited datasets or coarse temporal resolutions, this research encompasses all 36 states of Nigeria, including the Federal Capital Territory, Abuja. It utilizes 15 years of daily wind data (2004-2018) and 5 years of hourly data (2019-2023) obtained from the Nigeria Meteorological Agency. This dual approach captures both long-term trends and short-term dy-

namics, providing a robust foundation for energy planning. The findings aim to guide policymakers, energy developers, and stakeholders involved in the Zero Generator Accelerator Program toward sustainable solutions that address Nigeria's energy deficit.

2. Methodology

The studies obtain data from the Nigeria Meteorological Agency (NIMET) covering the thirty-six states and the federal capital Abuja. The data of which are of two types, the first comprising 15 years (2004-2018) daily data and the second covering 5 years (2019-2023) of hourly data measured in knots.

Data processing involves:

Conversion of data from knot to m/s

$$\text{Wind speed (m/s)} = \text{Wind speed (knots)} \times 0.51444$$

This required conversion to meters per second (m/s) for consistency and comparability with international wind speed standards.

The Weibull distribution density function using the standard deviation method on Excel was used to analyze the wind data.

For the daily wind data:

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

where the k = shape parameter and c = scale parameter ($v \geq 0$, $k > 0$, $c > 0$).

using a statistical approach to obtain the optimal values for k and c .

The corresponding Weibull cumulative distribution function (CDF):

$$f(v) = 1 - \exp\left(-\left(\frac{v}{c}\right)^k\right) \quad (2)$$

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

where:

σ = standard deviation

v_m = mean wind speed

$$c = v_m(0.568 + 0.433/k)^{\frac{1}{k}} \quad (4)$$

Equations (5) and (6) were used to determine the monthly wind speed and standard deviation

$$\sigma = \left(\frac{\sum (v_i - v_m)^2}{n-1} \right)^{\frac{1}{2}} \quad (5)$$

$$v_m = \frac{1}{n} \sum_{i=1}^n v_i \quad (6)$$

v_i = represents each velocity on the data, v_m = average wind velocity, and n = number of measurements.

For wind resource assessment, especially when using hourly datasets, the wind speed frequency distribution is essential for predicting wind turbine power output. This distribution illustrates how frequently specific wind speeds occur within defined ranges or "bins," offering crucial insights into the potential power generation over time. The Weibull distribution is commonly employed to model these frequency distributions. (Adapted from *Wind Resource Assessment: A Practical Guide to Developing a Wind Projects*.)

The probability density function of the Weibull distribution is expressed as in equation (1), but here the v_m = Mean cubic velocity.

$$v_m = \left(\frac{\sum_{i=1}^n f_i v_i^3}{\sum_{i=1}^n f_i} \right)^{\frac{1}{3}} \quad (7)$$

$$c = \frac{v_m k^{2.6674}}{0.184 + 0.816 k^{2.73855}} \quad (8)$$

The scale parameter is adjusted by the shape parameter and represents the characteristic of the wind speed of the site.

$$\sigma = \sqrt{\frac{\sum_{i=1}^n f_i (v_i - v_m)^2}{\sum_{i=1}^n f_i}} \quad (9)$$

σ = the standard deviation formula showing the spread of wind around the mean, weighted by the frequency of each speed.

where represents the probability that a wind speed will occur within a unit-width bin, centered on v . In this formula, k (shape parameter) and c (scale parameter). These parameters are adjusted to ensure the Weibull model aligns with the site's observed data distribution, enabling accurate estimates of power output potential from wind resources (Brower, 2012).

Comparison with Other Research

Previous studies, such as Argungu et al. [3], analyzed wind energy potential in Jos using Weibull distributions but relied solely on daily data from a single location over a relatively short period of five years. Their approach yielded higher k values, indicating greater wind stability, but overlooked hourly fluctuations that are critical for turbine performance. Similarly, Odo et al. [7] assessed wind potential in South-East Nigeria using 10-year monthly averages, neglecting diurnal patterns and the national scope. It is important to note that using monthly wind speed data has limitations, such as masking extremely low or high wind speeds within the month and the inability to capture diurnal variations in wind speed

[5]. In contrast, our methodology integrates both daily and hourly datasets across all 36 states, providing a more granular and comprehensive analysis.

Recent studies have enhanced the assessment of Nigeria's wind energy potential by incorporating more comprehensive datasets and refined methodologies. For instance, a 2025 computational study published in the Journal of Engineering Research and Reports examined the feasibility of wind power in Sokoto State using hourly wind data from July and August 2023, combined with turbine aerodynamic modeling. This study accounted for diurnal fluctuations and efficiency factors, revealing how seasonal variations in wind speed affect power generation capacity and underscoring the importance of considering hourly and monthly patterns for accurate performance evaluation [10]. Similarly, a 2024 study on wind energy utilization in Ilorin, Kwara State, utilized a 15-year dataset of monthly average wind speeds measured at multiple altitudes, demonstrating distinct seasonal wind speed patterns and variations in wind power density that are critical for renewable energy planning in north-central Nigeria [11].

Moreover, monthly wind speed modeling in northwest Nigeria using advanced Exponential Autoregressive-Fractional Integrated Generalized Autoregressive Conditional Heteroscedasticity (ExAR-FIGARCH) models has revealed long-memory effects and volatility in wind speed data, thereby enhancing the understanding of wind speed behavior for energy prediction [12]. These studies address the limitations of earlier research that primarily relied on daily or monthly average data from limited locations and time periods, offering more granular and nationally representative assessments of wind resources.

Recent wind power density measurements from the Nigerian Meteorological Agency (NiMet) in early 2025 highlight significant regional variations. Northern states exhibit high wind power densities—up to 206 W/m²—making them favorable for large-scale wind energy projects. In contrast, southern and coastal regions show lower densities due to atmospheric and geographic factors [13]. These comprehensive datasets enable more precise targeting of wind farm developments in optimal zones, improving estimates of turbine performance and energy yield.

Altogether, the integration of hourly datasets, multi-altitude measurements, advanced statistical models, and national coverage represents a significant advancement in estimating Nigeria's wind energy potential over the past five years. This approach addresses previous limitations related to temporal resolution and spatial representation [10-13].

Our use of the Weibull distribution offers greater flexibility in modeling diverse wind regimes by accounting for variations in both shape and scale parameters. The incorporation of GIS mapping further distinguishes this study, enabling spatial visualization that is absent in most previous Nigerian wind research. This multifaceted approach

enhances the accuracy and applicability of the findings for national-scale energy planning.

3. Result

The results for the 36 states' locations, as shown in the table below, demonstrate that a reliable frequency distribution of wind speeds is essential for accurately estimating energy output from wind resources. The wind speed analysis reveals that most occurrences fall within the 1-4 m/s range. This distribution suggests limited power output potential for standalone wind turbines but indicates a viable supplementary role within a hybrid system when combined with solar energy.

Table 1. Data showing average windspeed in the North Central states of Nigeria.

North Central	K	c (m/s)	v (m/s)
Abuja	5.81	1.81	2
Benue	6.00	1.78	2
Ilorin	6.18	2.15	2
Jos	4.82	3.10	3
Kogi	6.24	2.03	2
Lafia	7.97	2.17	2
Minna	6.24	1.62	

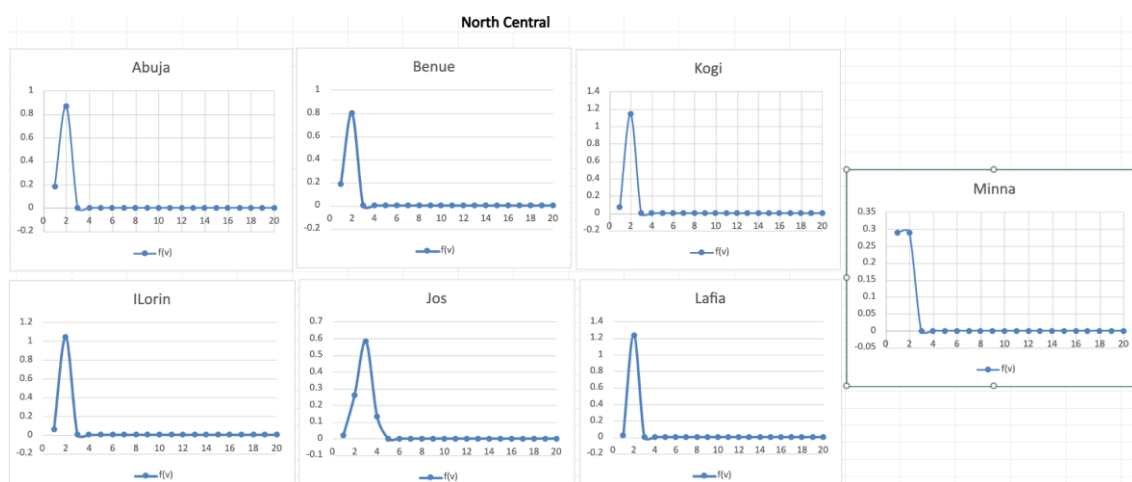


Figure 1. Average wind speed in the North Central states of Nigeria.

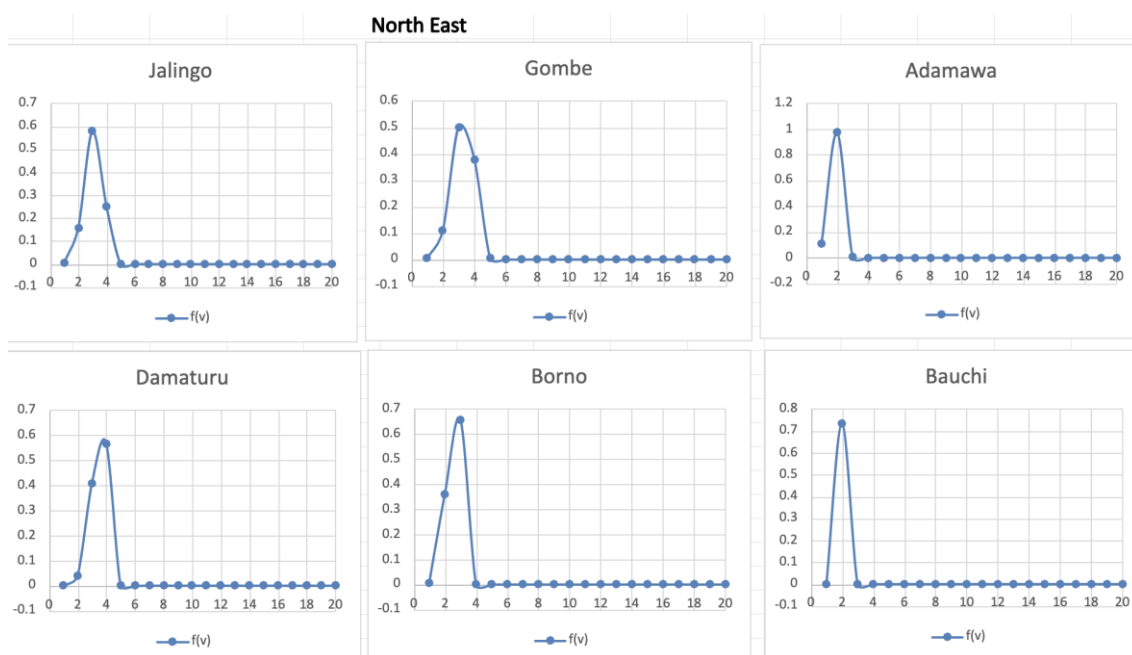


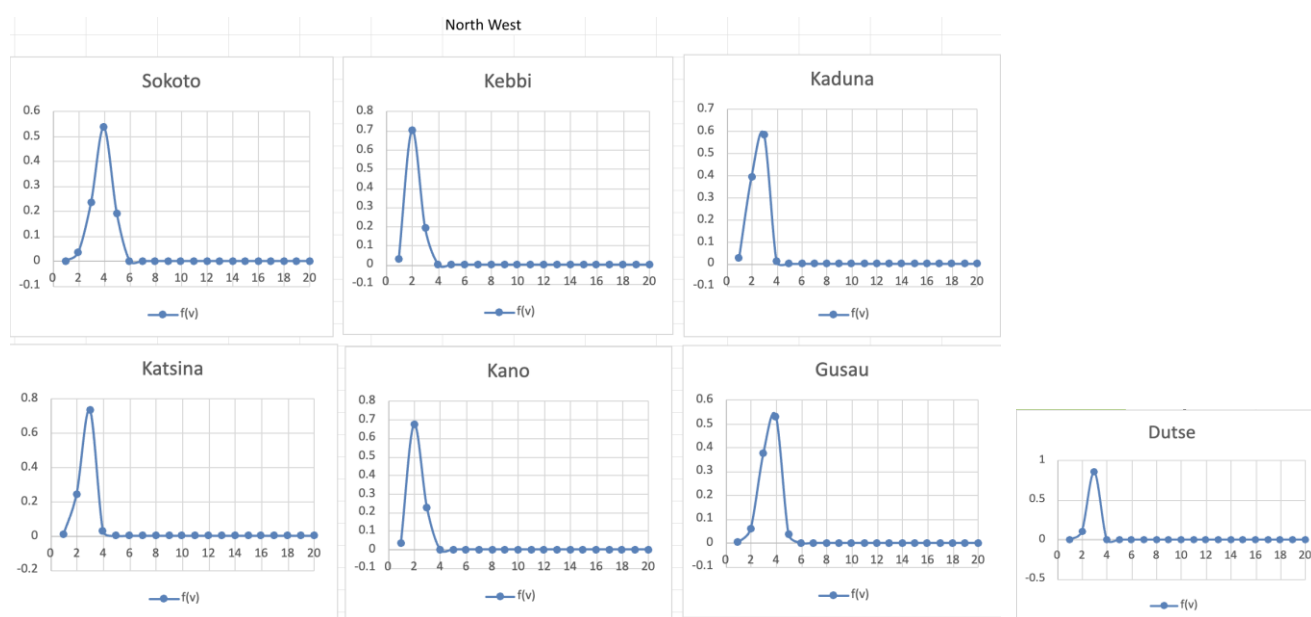
Figure 2. Average wind speed in the North-Eastern states of Nigeria.

Table 2. Data showing the average windspeed in the North-Eastern states of Nigeria.

North East	k	C	V (m/s)
Jalingo	5.42	3.34	3
Gombe	5.65	3.53	3
Damaturu	7.24	3.73	4
Borno	6.50	2.75	3
Adamawa	5.34	2.05	2
Bauchi	10.39	2.38	2

The k values for the North-East states range from 5.34 (Adamawa) to 7.24 (Damaturu). Higher k values indicate more consistent wind speeds, which is advantageous for maintaining steady power output from wind turbines. With the highest k value of 7.24, Damaturu exhibits the most stable wind profile among these states. This stability reduces variability in power output, making it ideal for wind energy production.

The scale parameter, c, ranges from 2.05 m/s in Adamawa to 3.73 m/s in Damaturu, indicating that the wind in this region is not only stable but also relatively strong. This makes it highly suitable for wind energy projects.

**Figure 3.** Average wind speed in the North Western states of Nigeria.**Table 3.** Data showing the average wind speed in the North-Western states of Nigeria.

North West	K	C	V (m/s)
Sokoto	6.03	4.19	4
Kebbi	5.94	2.41	2
Katsina	6.00	2.99	3
Kano	5.81	2.44	2
Kaduna	5.25	2.77	3
Gusau	6.06	3.81	4
Dutse	12.31	2.79	3

Sokoto and Gusau appear to be the most promising locations for standalone wind energy projects due to their relatively high average wind speeds and favorable scale parameter values. The consistent wind conditions in these areas can support continuous energy production, making these sites ideal for larger-scale wind farms.

Dutse exhibits exceptional stability in wind patterns, as indicated by its very high k value. This characteristic is advantageous for projects requiring consistent wind resources, although the lower k value suggests that wind strength may not be as high as in Sokoto and Gusau.

Kano, Kaduna, and Kebbi may have less favorable conditions for standalone wind projects due to lower average wind speeds. These regions could benefit more from hybrid renewable systems that combine both wind and solar resources to ensure a reliable energy supply.

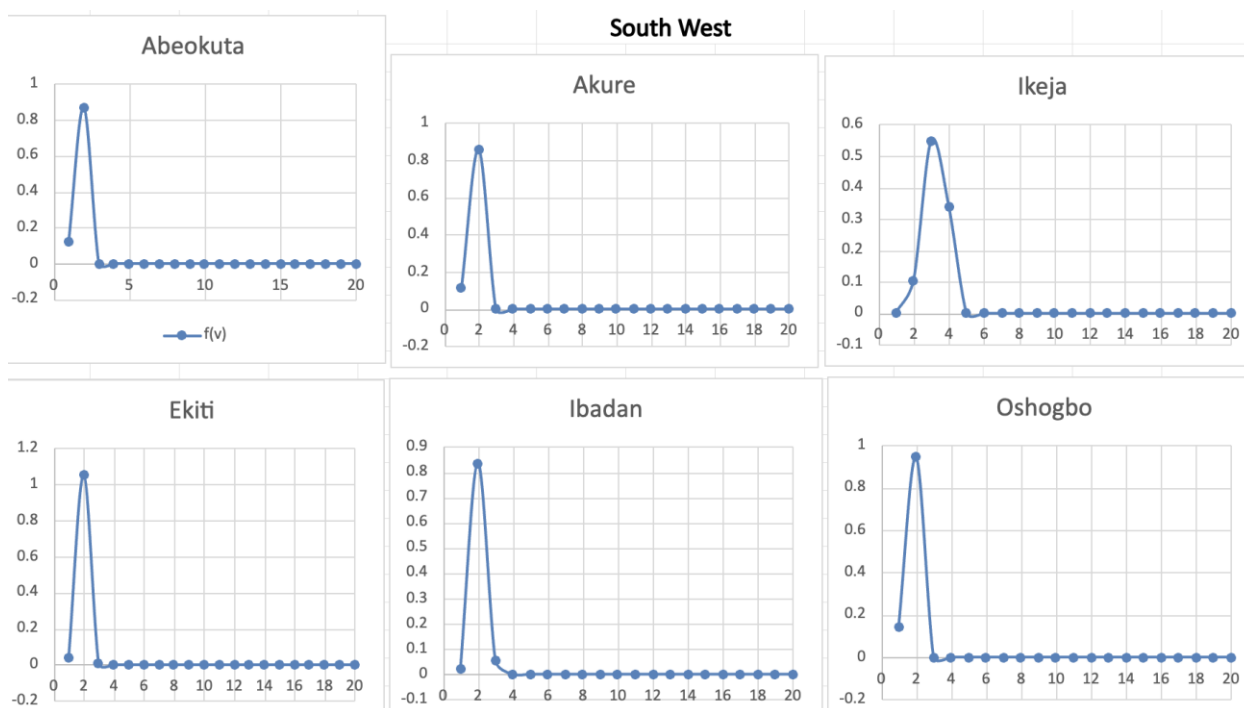


Figure 4. Average wind speed in the southwestern states of Nigeria.

Table 4. Data showing the average wind speed in the south-western states of Nigeria.

South West	K	C	V (m/s)
Abeokuta	6.87	1.79	2
Akure	6.44	1.86	2
Ekiti	6.59	2.19	2
Ibadan	6.69	2.33	2
Ikeja	6.01	3.47	3
Oshogbo	6.17	1.83	2

Ikeja appears to have the greatest wind energy potential within the South-West region due to its higher c -value and an average wind speed of 3 m/s. This makes it a favorable location for wind turbines, which require stronger winds to generate power. This advantage may be related to the location's proximity to the shore.

Abeokuta, Akure, Ibadan, Ekiti, and Oshogbo, characterized by lower shape parameter (c) values and average wind speeds, may face challenges if relying solely on wind energy. However, these locations could still contribute effectively to a hybrid renewable energy system, particularly when combined with solar energy, which is abundant in Nigeria. A statistical assessment of wind energy potential in Ibadan [14, 15], based

on the Weibull distribution model using 10 years of daily wind speed data (1995-2004), revealed that the site has an annual power density of approximately 12.55 W/m^2 and an average annual wind speed of 2.7 m/s. These conditions are suitable only for low-power applications such as battery charging and water pumping [15, 16], underscoring the need for a hybrid system to ensure seamless energy generation in these regions.

The relatively high k (shape parameter) values across the region are advantageous for project planning, as they indicate stable wind speeds. Although the average speeds are lower, this stability can still support consistent, albeit modest, energy generation. This output could be supplemented with solar energy to provide a reliable power supply.

Table 5. Data showing the average wind speed in the South-South states of Nigeria.

South South	K	C	V (m/s)
Asaba	6.10	1.90	2
Bayelsa	5.31	1.72	2
Benin	6.05	1.54	1
Port Harcourt	5.92	2.41	2
Calabar	9.02	1.91	2
Uyo	5.68	2.84	3

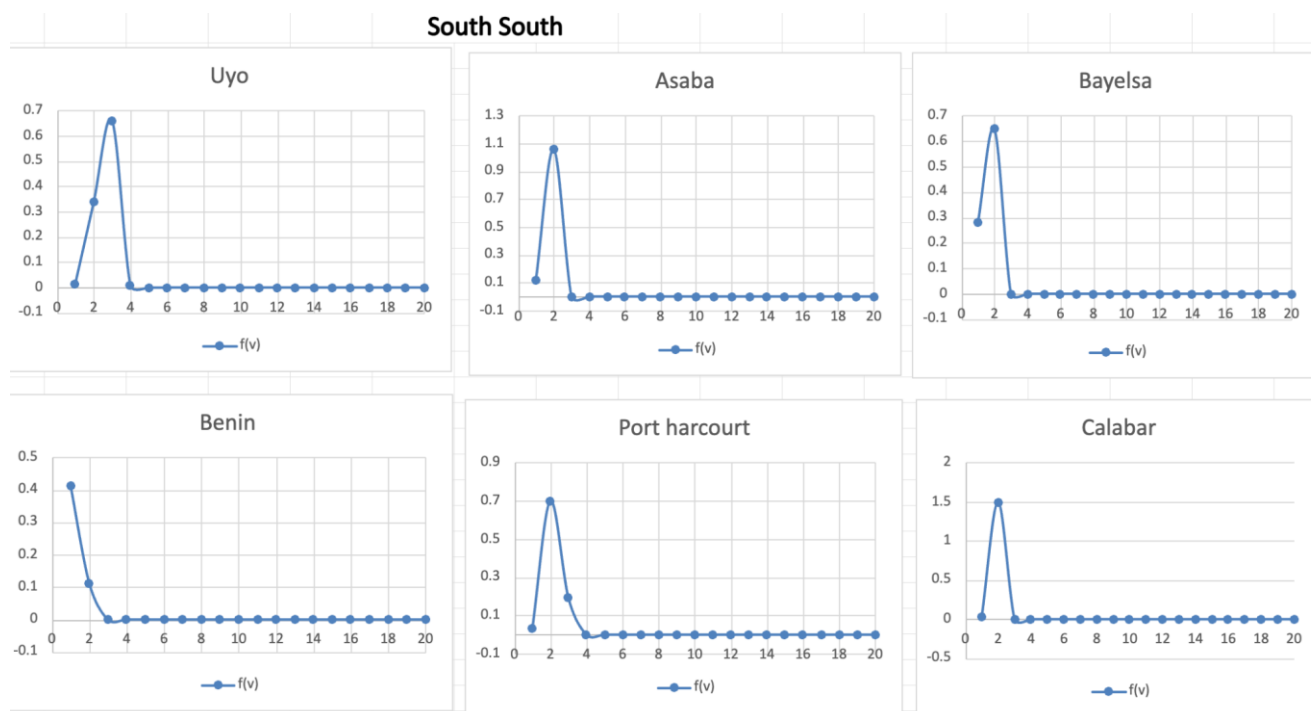


Figure 5. Average wind speed in the South South States of Nigeria.

The shape parameter k ranges from 5.31 in Bayelsa to a notably high 9.02 in Calabar, with an average value of 6.35. This narrow range indicates limited variation in wind speed, reflecting stable wind conditions. Calabar's k value of 9.02 signifies highly consistent wind speeds, which can improve the predictability of wind power output at this site. Additionally, wind speeds are generally weak in the southern region, except along the coastal and offshore areas, which experience stronger winds. Offshore zones extending from Lagos through Ondo, Delta, Rivers, Bayelsa, and Akwa Ibom States have been identified as having significant potential for harvesting strong wind energy year-round.

Other locations, such as Uyo (5.68) and Port Harcourt (5.92), exhibit moderate k values, indicating that although they experience fluctuations in wind speeds, the conditions remain sufficiently stable for viable wind energy generation.

Uyo and Calabar offer the most favorable conditions for wind energy generation in the South-East. Uyo's high scale parameter and average wind speed, combined with Calabar's high shape parameter (k), indicate that these locations could support small-scale wind energy projects with consistent output.

Benin and Bayelsa, characterized by lower scale parameter (c) values and reduced wind speeds, may find standalone wind

energy projects less feasible. Integrating wind energy with solar resources would likely be advantageous in these regions, particularly because solar irradiance is generally high in Nigeria, offering a complementary energy source to compensate for lower wind speeds.

The high shape parameter values across most states in the Southeast are advantageous for predictable energy output, reinforcing the potential for a hybrid energy strategy in which wind energy can play a consistent, if not primary, role.

Table 6. Data showing average wind speed in the south eastern states of Nigeria.

South East	K	C	V (m/s)
Imo	6.40	1.58	1
Umuahia	6.10	2.56	2
Enugu	5.91	1.85	2
Anambra	6.04	1.84	2
Abakaliki	6.17	1.88	2

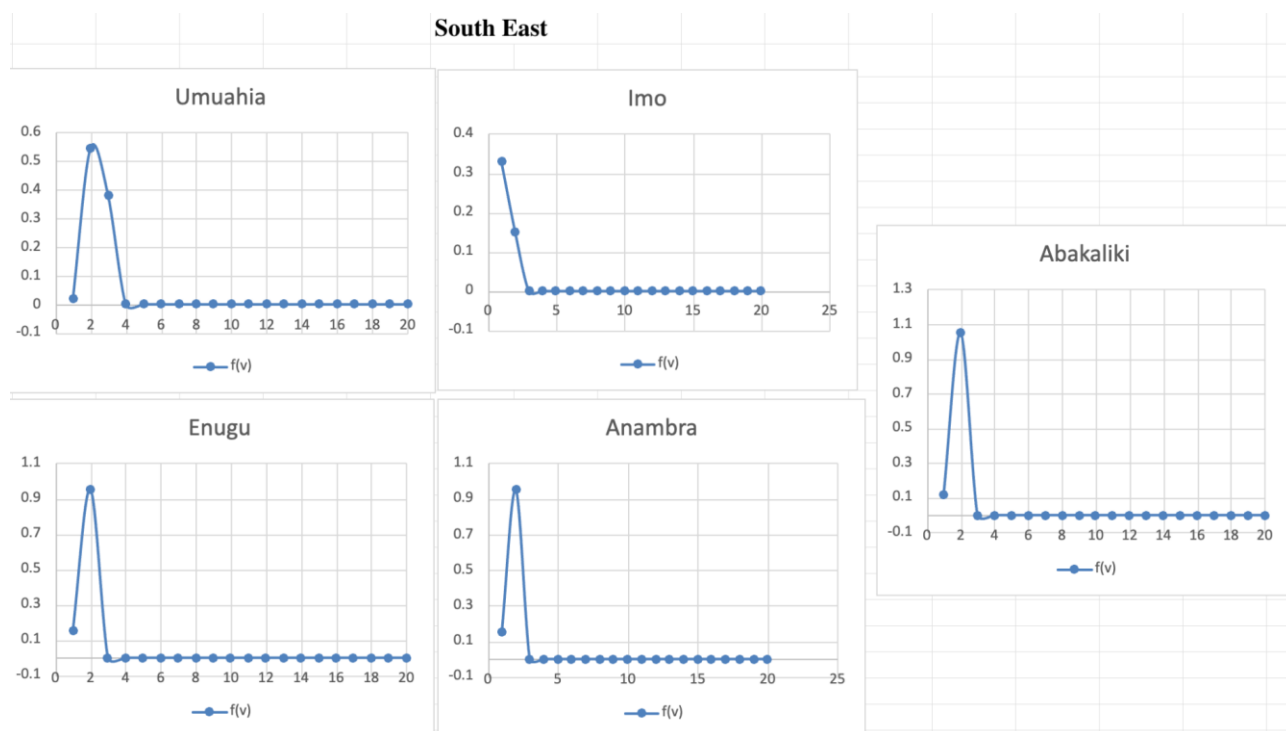


Figure 6. Average wind speed in the South eastern states of Nigeria.

The k values for the southeastern region range from 5.91 in Enugu to 6.40 in Imo, with an average of 6.12. Higher k values indicate more consistent wind speeds, though not necessarily stronger winds. Imo's shape parameter of 6.40 suggests stable wind conditions, which are advantageous for maintaining steady and predictable power output.

The scale parameter (c) values range from 1.58 in Imo to 2.56 in Umuahia, with an average of 1.94. The higher c value in Umuahia suggests stronger wind speeds compared to other locations in the region. Generally, scale parameters below 3 m/s, as observed here, indicate that wind speeds may be in-

sufficient for large-scale wind power generation; however, they could still support small-scale or hybrid renewable energy solutions.

Average wind speeds range from 1 m/s in Imo to 2 m/s in other states such as Umuahia, Enugu, and Abakaliki, with a regional average of 1.8 m/s. This range is relatively low for wind energy, as typical utility-scale wind turbines require speeds above 4 to 5 m/s for efficient power generation. Consequently, these states may benefit more from a hybrid approach that integrates wind and solar energy.

Hourly Data

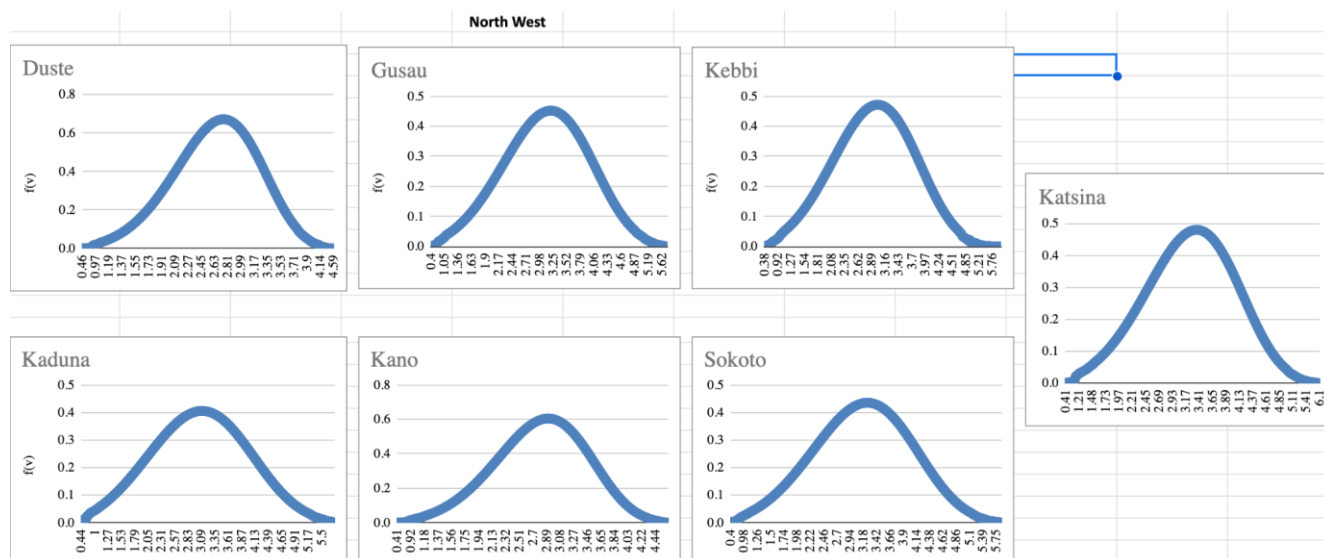


Figure 7. Northwest hourly time data.

Table 7. Average wind speed for north western states from hourly time data.

North West	K	C	V (m/s)
Sokoto	4.00	3.50	3
Kebbi	4.00	3.22	3
Katsina	4.52	3.56	3
Kano	4.91	3.05	3
Kaduna	3.58	3.39	3
Gusau	4.08	3.59	3
Dutse	5.13	2.87	3
Average	4.32	3.31	3

Similarities with the Daily Northwest Data

Both datasets consistently report an average wind speed of about 3 m/s across the Northwest region. This consistency shows that the region experiences fairly stable wind speeds, whether analyzing daily or hourly data.

The (k) values in both datasets indicate moderate variability in wind speeds, suggesting a relatively predictable wind pattern. In the daily dataset, (k) averages 6.77, while in the hourly dataset, it averages 4.32. Although these values differ, both show variability that can be effectively managed for energy generation. Additionally, both datasets highlight the region's suitability for hybrid systems combining wind and solar resources, given the relatively low wind speeds.

Differences

Higher (k) values, averaging 6.77, indicate less variability and a tighter distribution of wind speeds, implying more consistent wind behavior over daily periods. In contrast, lower (k) values, averaging 4.32, reflect greater variability in hourly wind speeds, likely influenced by daily and local atmospheric conditions.

The (c) parameter for daily data averages 3.06 m/s, slightly lower than in the hourly dataset, suggesting that the typical wind speeds measured daily are lower than those captured hourly.

While the (c) parameter averages 3.31 m/s on an hourly basis, indicating a slightly higher characteristic wind speed due to shorter measurement periods, the hourly dataset captures more detailed fluctuations, providing better insights into wind speed dynamics. In contrast, the daily dataset smooths out these variations, giving a more general overview.

Hourly Data Strengths: The higher time resolution of the hourly dataset makes it better suited for designing systems that need detailed operational data, such as wind turbine performance or daily energy planning.

Daily Data Strengths: The daily dataset is more useful for long-term resource assessment and strategic energy planning, as it provides a summarized view of wind energy potential over longer periods.

Daily Northwest Data

Both datasets consistently report an average wind speed of

approximately 3 m/s across the Northwest region. This consistency indicates that the region experiences relatively stable wind speeds, regardless of whether daily or hourly data are analyzed.

The (k) values in both datasets indicate moderate variability in wind speeds, suggesting a relatively predictable wind regime. In the daily dataset, (k) averages 6.77, while in the hourly dataset, it averages 4.32. Although these values differ, both reflect variability that can be effectively managed for energy generation. Additionally, both datasets underscore the region's suitability for hybrid systems that combine wind and solar resources, given the relatively low wind speeds.

Differences

Higher (k) values, averaging 6.77, indicate less variability and a tighter distribution of wind speeds, suggesting more consistent wind behavior over daily intervals. In contrast, lower (k) values, averaging 4.32, reflect greater variability in hourly wind speeds, likely influenced by diurnal and local atmospheric conditions.

The (c) parameter for daily data averages 3.06 m/s, slightly lower than in the hourly dataset, suggesting that the characteristic wind speeds measured daily are lower than those captured hourly.

While the (c) parameter averages 3.31 m/s on an hourly basis, reflecting a slightly higher characteristic wind speed due to shorter measurement intervals, the hourly dataset captures finer fluctuations, providing more detailed insights into wind speed dynamics. In contrast, the daily dataset smooths out these variations, offering a more generalized perspective.

Hourly Data Strengths: The higher temporal resolution of the hourly dataset makes it more suitable for designing systems that require detailed operational inputs, such as wind turbine performance modeling or diurnal energy supply planning.

Daily Data Strengths: The daily dataset is more suitable for long-term resource assessment and strategic energy planning, as it offers an aggregated view of wind energy potential over extended periods.

North Central

Table 8. Average windspeed from North Central hourly data.

North Central	k	c	V (m/s)
Abuja	3.7	2.1	2
Jos	3.4	2.8	2.6
Kogi	3.6	2.5	2.4
Lafia	4	2.2	2.1
Benue	4	1.2	1.9
Minna	2.6	2.6	2.3
Ilorin	2.8	4.2	2.7

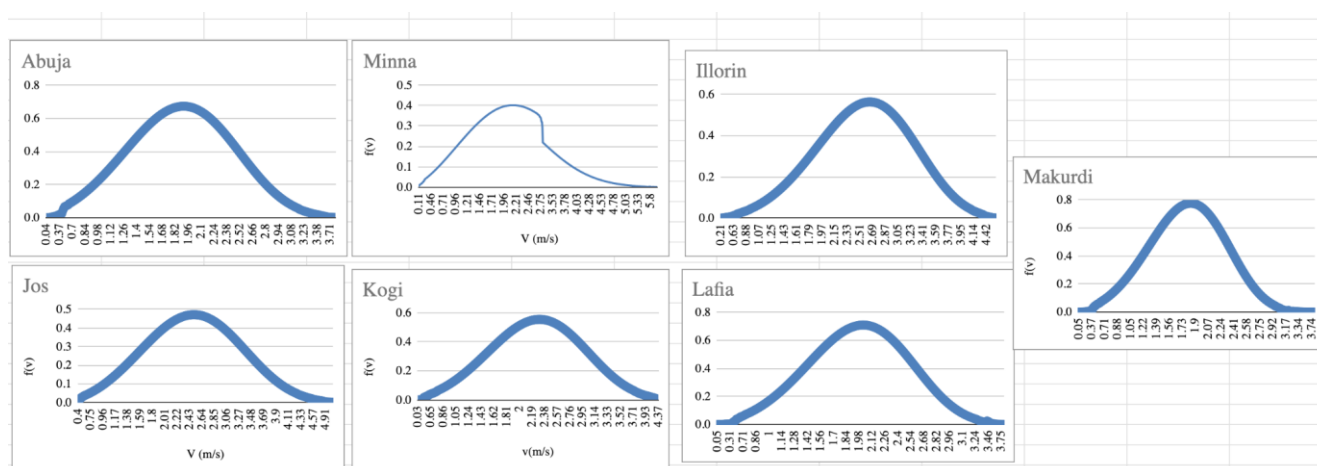


Figure 8. North Central hourly time data.

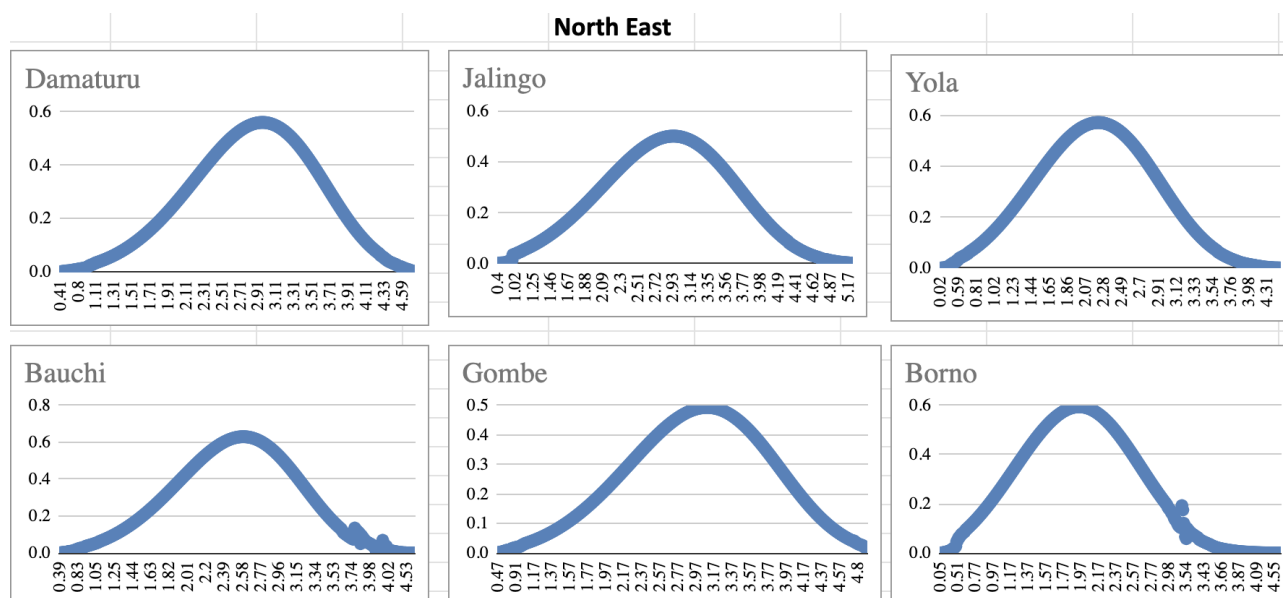


Figure 9. North East hourly time data.

Table 9. Average windspeed from North East hourly data.

North East	k	c	V (m/s)
Jalingo	4.13	3.13	3
Gombe	4.27	3.28	3
Damaturu	4.61	3.11	3
Borno	3.34	2.17	2
Adamawa	3.59	2.42	2
Bauchi	4.55	2.73	3

Both datasets for daily and hourly suggest that the North

East experiences moderate wind speeds. Both hourly and daily data show consistent wind characteristics across locations like Gombe and Damaturu, which have slightly higher wind potentials than others.

The difference arises from the mean wind speed (V) of the daily data, showing slightly higher average wind speeds (3.00 m/s) compared to the hourly data (2.67 m/s). This may be attributed to time-related averaging, where daily data captures peak winds better than hourly measurements.

The shape parameter (k) of the daily data has a higher k value (5.65) compared to hourly data (4.08), indicating that wind speeds are more consistent when observed daily, whereas hourly data captures more variability in short-term fluctuations.

For the Scale Parameter (c), The c value for daily data (3.53 m/s) is also higher than for hourly data (2.81 m/s). This suggests that the daily dataset reflects stronger characteristic

wind speeds, likely due to temporal smoothing effects.

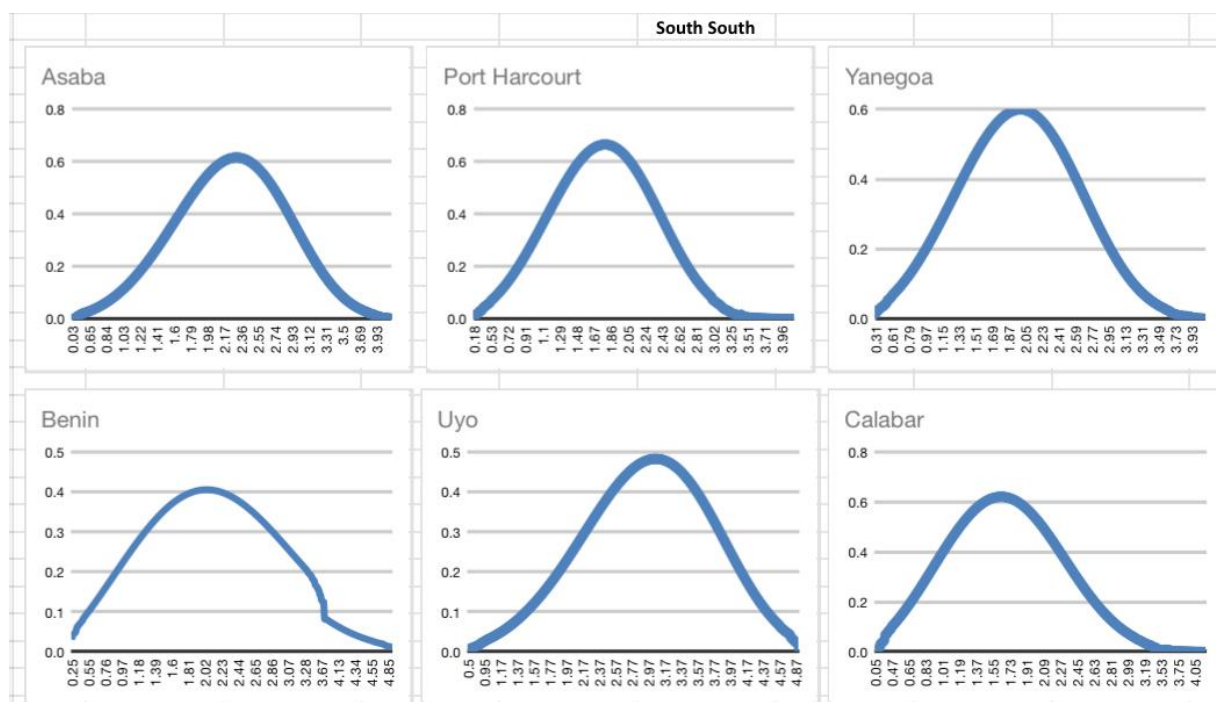


Figure 10. South South hourly time data.

Table 10. Average wind speed from south south hourly time data.

South South	K	c	V (m/s)
Asaba	4.01	2.48	2
Yenagoa	3.43	2.21	2
Benin	2.51	2.50	2
Port Harcourt	3.43	1.99	2
Calabar	2.97	1.88	2
Uyo	4.16	3.27	3

The average wind speed is relatively low across the region, with all locations falling around 2 to 3 m/s. Uyo shows the highest value at 3 m/s, suggesting slightly better wind potential compared to other cities. The k values range between 2.51 and 4.16. Higher k values in locations like Uyo and Asaba indicate more consistent wind speeds over time, while cities like Benin 2.51 reflect greater variability in wind conditions.

The scale parameter, which characterizes the wind distribution's scale, averages at around 2.39 m/s. Uyo again stands out with the highest c value of (3.27) m/s, reflecting a stronger characteristic wind speed.

Locations like Uyo and Asaba exhibit relatively better wind

characteristics, with higher k and c values indicating steadier and slightly stronger wind conditions.

Low Overall Potential: The general wind speeds across the region are low, which may limit the feasibility of large-scale wind energy projects without significant technological advancements in low-speed turbine efficiency.

This data can guide localized renewable energy strategies. Cities with better wind characteristics, such as Uyo, could be prioritized for small-scale wind turbine deployments. However, alternative renewable sources like hybrid renewable systems might provide better returns given the region's wind limitations.

Table 11. Average wind speed from south west hourly time data.

South West	K	C	V (m/s)
Abeokuta	3.77	2.44	2
Akure	3.61	2.10	2
Ekiti	4.49	2.28	2
Ibadan	3.47	2.21	2
Ikeja	4.52	3.77	3
Oshogbo	3.93	2.30	2
Average	3.96	2.52	2

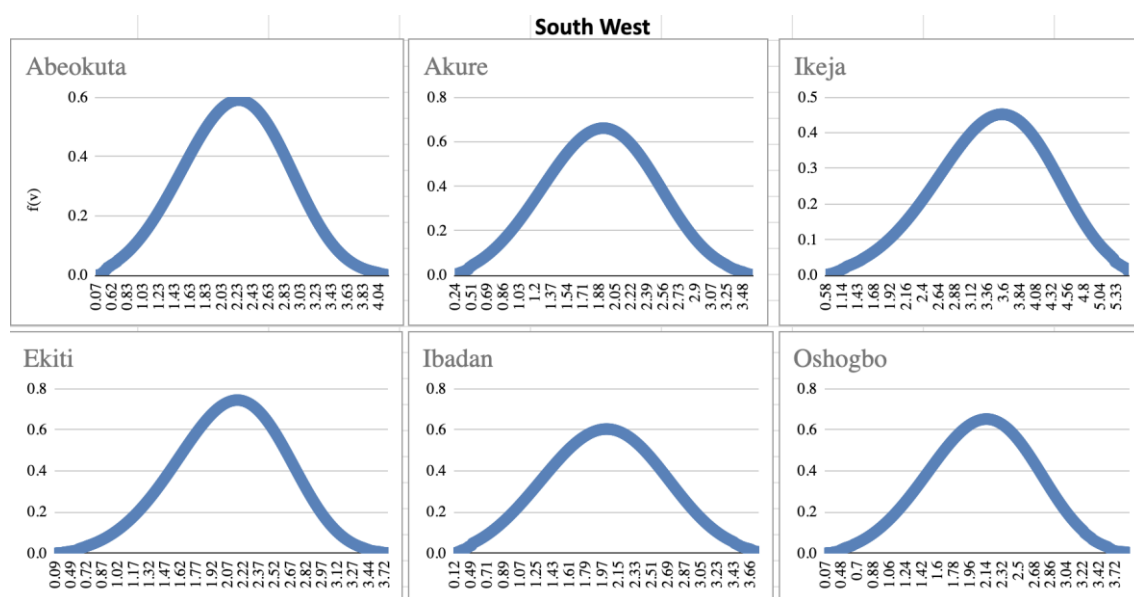


Figure 11. South west hourly time data.

The South West hourly wind data indicates moderate variability and generally low wind speeds, reflecting the region's limited wind energy potential. The shape parameter k values range from 3.47 to 4.52, with an average of 3.96, suggesting moderately variable wind conditions across the locations. The scale parameter c averages 2.52 m/s, with individual values ranging from 2.10 m/s (Akure) to 3.77 m/s (Ikeja), highlighting modest wind strengths. The average wind speed v across the region is 2 m/s, consistent with the relatively weak wind profile, except for Ikeja, which shows slightly higher potential (3 m/s). This dataset indicates the South West's challenges in leveraging wind energy for large-scale applications.

The comparison between the South West hourly and daily wind data reveals subtle differences in wind characteristics, reflecting the resolution and variability captured by each dataset. The hourly data shows a slightly lower average scale

parameter ($c = 2.52$ m/s compared to the daily data $c = 2.25$ m/s, indicating marginally stronger winds in the hourly resolution. However, the average wind speed v is consistent across both datasets at approximately (2 m/s), highlighting the region's weak wind energy potential overall.

The shape parameter k averages 3.96 in the hourly data and 6.46 in the daily data, suggesting greater variability in the hourly dataset. This difference is expected, as hourly measurements capture more short-term fluctuations compared to the smoothed daily averages. Locations like Ikeja exhibit a consistent trend of higher wind speeds and energy potential across both datasets, while others, such as Akure and Osogbo, remain stable at the lower end of the spectrum. These findings underline the South West's challenges for wind energy development, with limited potential evident in both temporal resolutions.

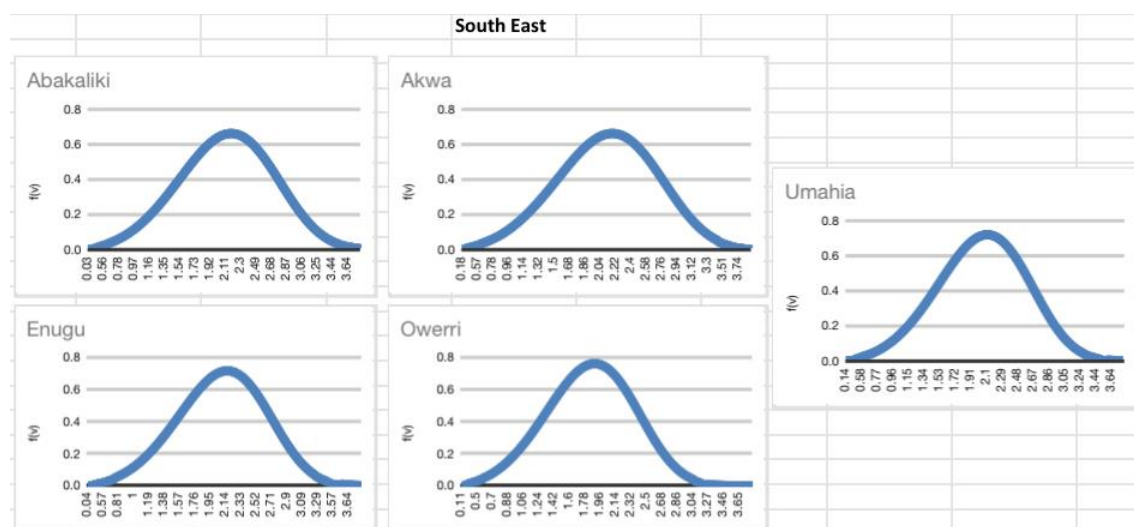


Figure 12. South East hourly data.

Table 12. Average wind speed from the southeast hourly data.

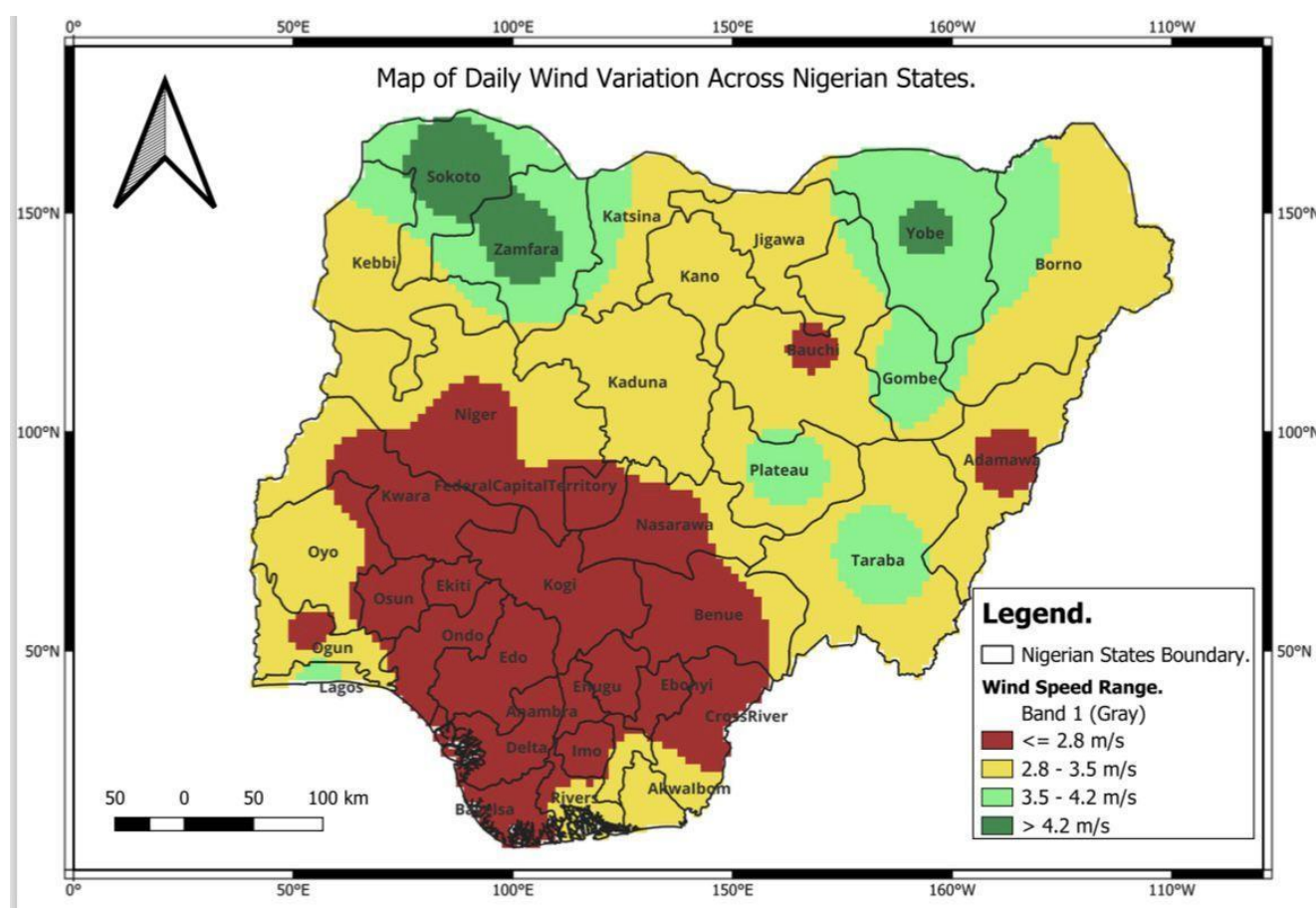
South East	K	c	V (m/s)
Imo	4.07	2.04	2
Umuahia	4.28	2.25	2
Enugu	4.35	2.30	2
Anambra	4.08	2.34	2
Abakaliki	4.08	2.34	2
Average	4.17	2.26	2

The Southeast hourly wind dataset, compared to its daily counterpart, reveals several key similarities and differences in wind characteristics across the region.

Both datasets show low average wind speeds, $V = 2$ m/s, indicating limited wind energy potential. Regions such as

Enugu and Abakaliki consistently exhibit relatively higher wind speeds, demonstrating a persistent pattern regardless of temporal resolution. The shape parameter k also indicates a relatively stable wind profile, with minor variability observed in both hourly and daily assessments.

The hourly data show a slightly lower average shape parameter, $k = 4.17$, compared to the daily dataset, $k = 6.12$, reflecting smoother wind distributions at the daily level, likely due to averaging effects. The scale parameter, c , for the hourly dataset is 2.26 m/s, slightly lower than the daily data value of 2.34 m/s, indicating marginally weaker winds on an hourly basis. These differences highlight that hourly data better capture short-term fluctuations, while daily data smooth these variations to present broader trends. Although the South-South region shows limited wind energy potential in both datasets, the hourly data provide more detailed insight into short-term wind variability, which could be crucial for fine-tuned wind resource assessments or microclimate studies.

**Figure 13.** Geographical Information System (GIS) mapping for the daily wind variation across Nigeria.

The daily GIS map highlights regions with varying wind speed ranges, showing that areas such as the Northern region and parts of the Middle Belt exhibit moderate wind speeds

(3.5-4.2 m/s), which are optimal for small-scale wind energy applications.

Southern states, especially those in the South-South and

South-West regions, exhibit lower wind speeds (below 2.8 m/s), indicating limited potential for wind energy generation

under typical daily conditions.

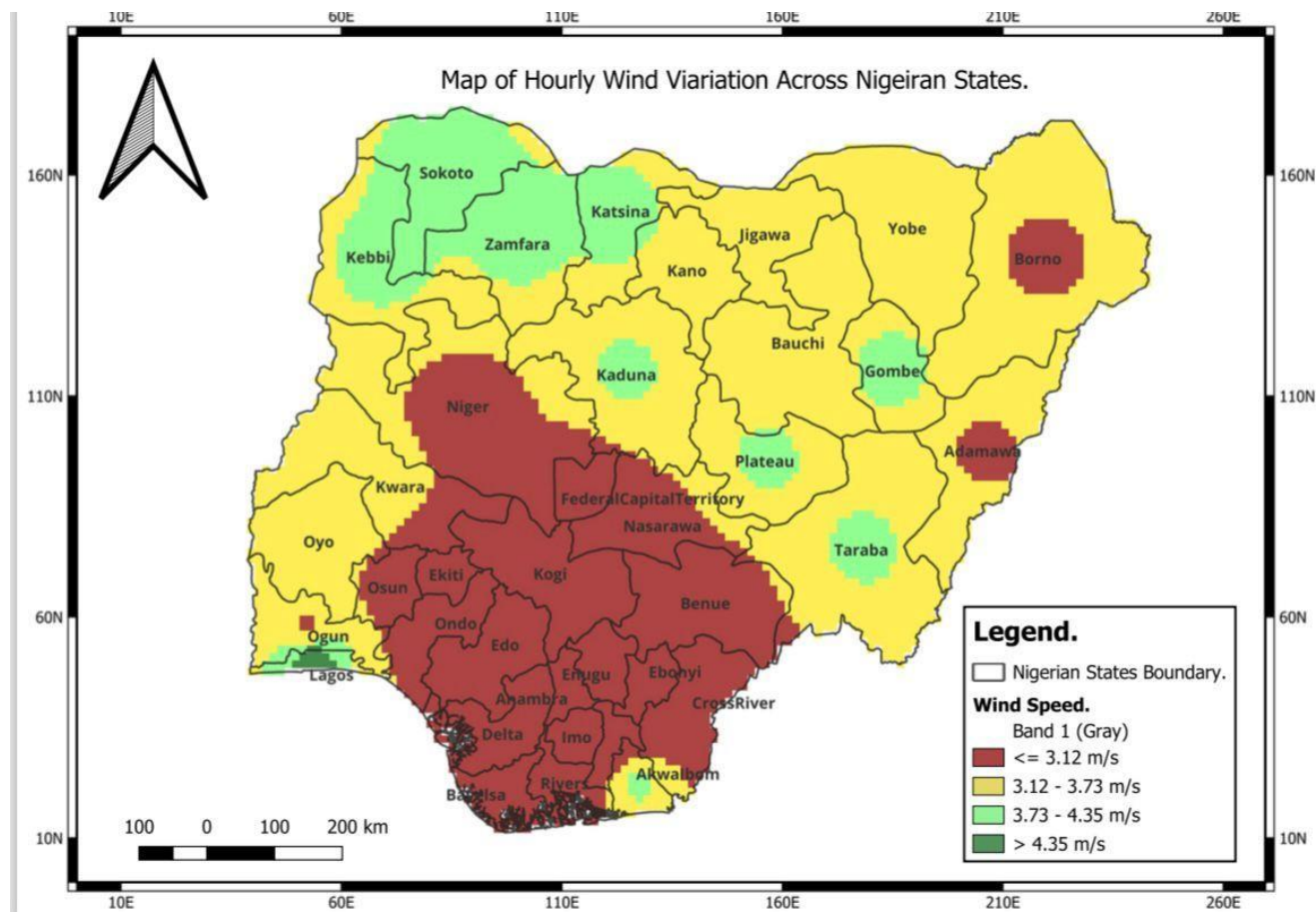


Figure 14. Geographical Information System (GIS) mapping for the hourly wind variation across Nigeria.

The hourly GIS map shows slightly higher wind speeds across most regions compared to the daily averages, indicating temporary variability and the potential to harness wind energy during specific times of the day.

The North-East and North-West regions, along with parts of the North-Central region, consistently exhibit higher wind speeds (>3.5 m/s), underscoring their suitability for wind energy projects.

South-South and South-West regions remain within the lower wind speed range, indicating minimal variation between hourly and daily wind conditions.

The GIS analysis confirms a geographical disparity in wind speed potential, with northern regions exhibiting higher wind speeds that are suitable for wind energy applications. The insights from hourly wind speed data generally exceed daily averages, providing potential opportunities for energy capture at specific times.

4. Discussion

The findings from the wind energy analysis across Nige-

ria's regions reveal distinct wind patterns and average speeds that influence the feasibility of standalone wind energy projects. In the Northwest region, the average shape parameter (k) of 6.77 and scale parameter (c) of 3.06, along with an average wind speed of 4.2 m/s, indicate moderate wind speeds with a stable distribution, particularly in states such as Sokoto and Gusau. These wind characteristics could support small-scale wind installations; however, hybridization with solar energy would likely improve energy consistency and output.

In the Northeast, which has an average shape parameter (k) of 5.86 and scale parameter (c) of 2.88, the wind speed averages approximately 3.5 m/s, with some locations, such as Damaturu, reaching up to 4 m/s. These wind speeds are more favorable for wind power generation compared to other regions, making the Northeast a viable candidate for small-scale wind projects or hybrid energy systems. The stability of wind patterns in this region, as indicated by moderate shape and scale values, further enhances its potential for consistent energy output when combined with solar resources.

The Southwest region, with a shape parameter (k) of 6.46, a scale parameter (c) of 2.25, and an average wind speed of 2.17

m/s, exhibits relatively low wind energy potential. However, the higher stability of wind patterns, as indicated by the shape parameter, suggests that wind conditions are consistent over time. Despite this stability, the low wind speeds may limit the feasibility of standalone wind energy generation. Nevertheless, the region's wind characteristics could be effectively utilized in hybrid energy systems, where solar power compensates for the limited wind energy contribution.

Similarly, in the Southeast, the average wind speed is approximately 2.00 m/s, with shape (k) and scale (c) parameters of 6.35 and 2.05, respectively, indicating low but stable wind conditions. This stability makes the region more suitable for hybrid energy systems, as standalone wind power generation would be inadequate. The South South region, which has the lowest average wind speed of 1.80 m/s and shape and scale parameters of 6.12 and 1.94, respectively, exhibits minimal potential for wind energy projects. Although its stable wind pattern suggests consistency, the wind speeds are insufficient to support standalone wind energy production, favoring hybrid solutions where solar energy can provide a substantial portion of the energy supply.

5. Conclusion

The North West and North East regions demonstrate slightly better prospects for wind energy projects, particularly in areas with higher wind speeds. However, the generally low wind speeds across most regions highlight the necessity for hybrid energy systems that integrate both wind and solar resources to deliver a reliable and sustainable energy solution. This approach capitalizes on the complementary strengths of wind and solar energy, especially in regions where standalone wind generation would be unfeasible.

Hourly data provides detailed insights into short-term variability and is crucial for real-time energy optimization and forecasting. However, it may underestimate the potential of wind power due to lower average wind speeds. In contrast, daily data captures long-term trends and higher average wind speeds, making it more suitable for feasibility studies and turbine selection. It offers a clearer picture of the overall wind resource potential for planning purposes.

Abbreviations

CREST	Center for Renewable Energy and Sustainable Transition
GIS	Geographical Information System
NIMET	Nigerian Meteorological Agency
ZE-GEN	Zero Emissions Generator

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Author Contributions

Nurudeen Issa: Conceptualization, Funding acquisition, and Resources.

Abdullahi Audu Adamu: Methodology, Validation, Resources.

Mustapha Muhammad Ibrahim: Data analysis, Software utilization, Methodology.

Shalom Iboh: Investigation, Literature review, Data analysis.

Fortune Voke Riagbayire: Writing—Review and Editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



Nurudeen Issa is the Founder and CEO of Sirius-X Energy, a renewable energy company dedicated to expanding clean energy access across Sub-Saharan Africa. He is a passionate climate activist and advocate for local manufacturing. Nurudeen has received multiple prestigious awards, including the Falling Walls Lab Competition and recognition at the Nigeria International Energy Summit for leading Nigeria's most outstanding solar-wind hybrid innovation. He has represented Nigeria at global events such as the Falling Walls Science Summit in Germany and the One Young World Summit in Northern Ireland as a bp NetZero scholar. Additionally, he won the Best Climate Mitigation Startup award through the UNIDO-backed GCIP. Nurudeen played a critical role in raising \$1.1 million for a solar-wind hybrid project in Nigeria, serving as the technical lead for the Innovate UK-funded initiative. He led the deployment of remote weather stations and analyzed decades of solar and wind data to support the deployment of clean energy.



Abdullahi Audu Adamu is a Professor of Mechanical Engineering and the immediate past Head of the Department (2022-2024) in the Department of Mechanical Engineering at Bayero University, Kano, Nigeria. He specializes in Energy Engineering, with a focus on both conventional and renewable energy systems and their simulations. He has successfully supervised numerous projects, theses, and dissertations at the undergraduate, master's, and PhD levels and has served as an external examiner for many universities at these levels of study. To his credit, he has authored approximately 40 journal publications, 15 conference papers, and co-authored a book on Wind Turbine Development. He is a registered corporate member of several professional organizations, including the Nigerian Society of Engineers (NSE), the Council for the Regulation of Engineering in Nigeria (COREN), the Nigerian Institution of Mechanical Engineers (NIMechE), and the Solar Energy Society of Nigeria (SESAN).



Mustapha Muhammad Ibrahim is a dedicated AI practitioner with a Bachelor's degree in Computer Engineering from Bayero University, Kano. His undergraduate thesis focused on anomaly detection in electricity fraud using machine learning. He currently serves as Lead Data Analyst/Scientist at Sirius-X Energy, where he has led the analysis of wind and solar radiation datasets across Nigeria. Previously, he interned at the National Center for Artificial Intelligence and Robotics (NCAIR), where he gained in-depth experience in machine learning, embedded systems, and 3D printing technologies. A Nigeria Higher Education Foundation Scholar and Student Energy Fellow, Mustapha is passionate about advancing technological solutions that are not only innovative but also deeply rooted in addressing real-world problems with empathy, sustainability, and impact at their core.



Shalom Chilaru Iboh is the founder of Renew Watts Technologies. Under her leadership, the organization has mobilized climate advocates and energy educators to implement projects that have impacted over 6,000 people across more than 46 countries. She is currently pursuing a PhD in Chemical Engineering. Shalom's doctoral research integrates multi-physics simulations, mathematical modeling, optimization, techno-economic analysis, life cycle assessment, and deep learning models to develop cost-effective and sustainable novel renewable jet fuel and diesel derived from bio-based feedstocks. Her scientific contributions have earned her the 2025 Graduate Rising Star-Southeast Region Award, recognition as a 3 Minute Thesis finalist, and designation as a Rising Solar Fellow by WRISE. Additionally,

Shalom has held pivotal roles, including Data Analyst—where she analyzed wind energy data—and Gender Equality and Social Inclusion Strategist. In this capacity, she championed gender action plans and successfully promoted gender equality, disability inclusion, and the participation of marginalized groups in renewable energy advancement, leadership, and sustainability initiatives.



Fortune Voke Riagbayire is a passionate advocate for clean energy, deeply committed to advancing the Sustainable Development Goals. He holds a bachelor's degree in Mechanical Engineering from Bayero University Kano. Currently, he serves as the Chief Technology Officer at Let-It Cold Nigeria Limited, where he has led multiple projects implementing solar-powered refrigeration systems in Northern Nigeria. As an innovator and researcher, Fortune specializes in providing alternative energy solutions for cooling and clean cooking, aiming to alleviate energy poverty and accelerate the transition to a sustainable energy future. He received an award of recognition for his presentation on biogas as an alternative energy source for cooking at the International Conference on Innovation in Science and Engineering (ICISE)

in Kuala Lumpur, Malaysia. Leveraging his expertise, he delivers exceptional energy audit services, offering clients valuable recommendations to reduce daily energy consumption and minimize their carbon footprints.

Research Field

Nurudeen Issa: Solar and Wind Energy Integration, Climate Policy, Green Hydrogen, Climate Finance, and Renewable Energy Technologies.

Abdullahi Audu Adamu: Energy Engineering, Wind Energy Development, Conventional Energy Systems, Numerical Methods, and Renewable Energy Systems.

Mustapha Muhammad Ibrahim: Machine Learning, Data Analytics, Cloud Computing, AI for Renewable Energy, and AI for Good/Social Impact.

Shalom Chilaru Iboh: Clean energy systems, Modeling, Simulation and Optimization, Machine Learning, Gender Equality and Social Inclusion (GESI) Strategist, Sustainability Analysis.

Fortune Voke Riagbayire: Bio-gas, Voluntary Carbon Markets, Energy Access, Decarbonization Pathways, Green Finance, Refrigeration and Air Conditioning.