

# Wind Power Capability Assessment in Kusada community, Katsina State, Nigeria: Utilizing the Weibull Distribution Method

<sup>1</sup>Yusuf, A., <sup>1</sup>Salisu, S., <sup>1</sup>Jibril, Y. and <sup>1</sup>Seidu, I.

Department of Electrical Engineering, Ahmadu Bello University, Zaria, Kaduna State Nigeria

## Paper History

Received: 15<sup>th</sup> Augt., 2024

Accepted: 01<sup>st</sup> Sept, 2024

Published: September, 2023

## Abstract:

This study evaluates the wind energy potential of Kusada, a community in Katsina State, Northern Nigeria, where renewable energy resources remain largely untapped. Using a decade-long dataset of wind speeds (2012-2021) obtained from the NASA website. This research employs the Weibull distribution to analyze wind characteristics and estimate wind power density at a height of 10 meters. The results indicate that the average wind speed in Kusada ranges from 1.65 to 3.34 m/s, with the highest average wind speed recorded in January. The Weibull scale parameter varies from 1.8084 m/s to 3.9598 m/s, while the shape parameter ranges from 7.1225 to 33.2363. The wind power density was determined utilizing the Weibull probability density function ranges from 3.75 W/m<sup>2</sup> to 37.68 W/m<sup>2</sup>, classifying the site as a Class 1 wind resource area. This classification suggests the area is not conducive for the deployment of wind turbines on a grand scale but feasible for small-scale, independent energy systems and mechanical uses such as battery charging and water pumping. Additionally, integrating wind energy into hybrid systems with solar, battery storage, and diesel generators is recommended. This study provides a comprehensive evaluation of Kusada's wind energy potential, contributing to the strategic development of renewable energy in rural Nigeria.

Corresponding author  
Seidu, I.

[oyarebu209@gmail.com](mailto:oyarebu209@gmail.com)

**Keywords:** Assessment, Kusada community, Power density, Renewable energy, Weibull distribution, Wind energy potential

## 1. Introduction

Energy is fundamental to life and development, serving as a crucial driver of economic growth. Adequate access to energy is essential for poverty alleviation and maintaining high living standards [1]. Although conventional energy sources like fossil fuels have significant environmental impacts, they remain primary sources of energy globally due to their crucial function in fulfilling energy needs. Uninterrupted utilization of these resources, however, exacerbates both living costs and environmental degradation through greenhouse gas emissions [2, - 4].

The rapid industrialization and population growth have heightened energy demands, resulting in the exhaustion of limited fossil fuel reserves and contributing to climate change. As a result, renewable energy sources are becoming growing more appealing as alternatives to overreliance on traditional energy sources. Global energy usage in the market is expected to rise by 57% between 2004 and 2030 [5, 6]. Despite this, a large portion of the world's energy generation and consumption is unsustainable with current technology.

In Nigeria, access to electricity remains limited, particularly in countryside regions with a population of around 10% has reliable power [7]. Approximately 51% of Nigerians reside in remote community with minimal without access to electrical power. This underscores the urgent need to develop and fully exploit renewable energy

resources to improve the energy mix. The country has abundant renewable resources, including small and large-scale hydropower, solar irradiance, wind, and biomass (e.g., fuelwood and plant and animal wastes) [8]. However, the evaluation and utilization of these resources, especially wind energy, are still underdeveloped [9, 10].

Wind energy is anticipated to be a significant component of future energy supplies in both Europe and globally. With thousands of wind turbines worldwide, totalling an installed capacity of 194.4 GW, wind power accounted for about 44% of this capacity in Europe as of the end of 2010 [11, 12]. In Nigeria, however, wind energy remains underutilized, and its development is limited. The choice of site and wind conditions are crucial for effective wind energy installation, impacting turbine performance and site suitability [13]. Precise tools for analyzing the potential of wind energy are essential for evaluating recoverable wind energy and selecting the optimal system for wind energy conversion to maximize output and reduce generation costs [14, 15].

This work aims to evaluate the potential for wind energy in Kusada, a small community in Katsina State, Northern Nigeria, addressing the need for research in this region where renewable resources remain largely untapped. Figure 1 clearly shows the location of Katsina State on the map of Nigeria.

## 2. Methodology and Materials

This section discusses the methods and materials explored for the successful completion of this research

### 2.1 Wind Data

Wind data spanning 10 years, from 2012 to 2021, were obtained for the Kusada community (12.4576°N, 7.9786°E) at a height of 10 meters from the NASA website. The data were collected on an hourly intervals to derive monthly wind velocities and other wind parameters.

### 2.2 Weibull distribution Parameters

Two frequently employed functions for fitting the probability distributions of measured wind speeds at a specific region over a given timeframe includes the Weibull and Rayleigh distributions [16, 17]. Only the Weibull distribution was utilized for this study, as it provides a better fit compared to the Rayleigh distribution.

The Weibull probability density function (PDF) is defined as in [16].

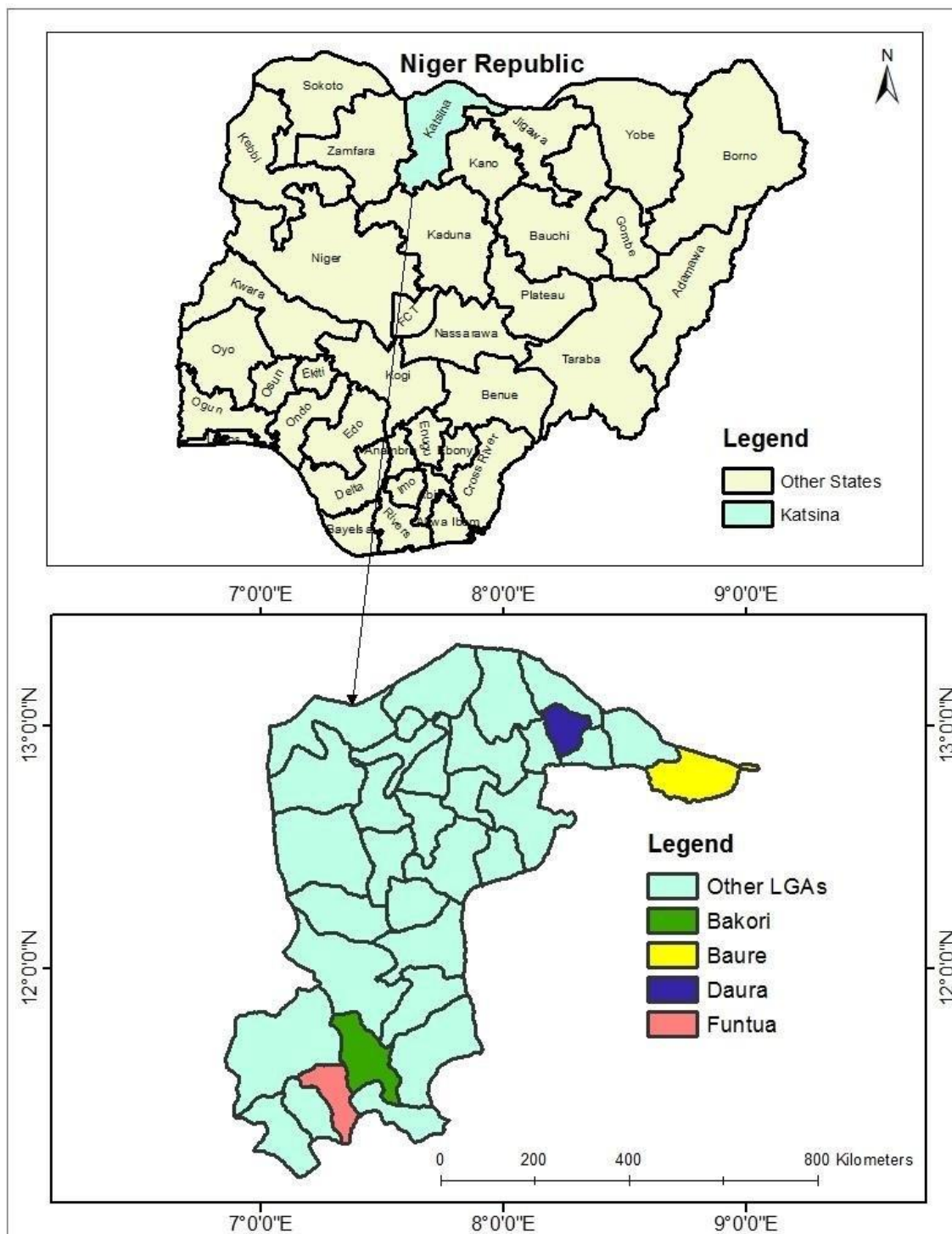


Figure 1. Map of Nigeria and an extraction showing Katsina State.

$$f(v) = \frac{k}{c} \cdot \left(\frac{v}{c}\right)^{a-1} \cdot B \tag{1}$$

$$F(v) = 1 - B \tag{2}$$

$$a = k - 1 \tag{3}$$

$$B = \exp\left[-\left(\frac{v}{c}\right)^k\right] \tag{4}$$

In this context,  $f(v)$  denotes the probability density function (PDF) for a given wind speed ( $v$ ). The parameter  $k$  refers to the dimensionless shape parameter of the Weibull distribution, while  $c$  represents the scale parameter in (m/s). Additionally,  $F(v)$  is the cumulative distribution function (CDF) for the observed wind speed? Various techniques are available for calculating the  $k$  and  $c$  parameters of the weibull. However, this paper utilizes the approximation method exclusively, as it offers more accurate predictions of wind speed and wind power compared to alternative approaches [17].

The  $c$  and  $k$  parameters of the Weibull function are provided as in [18]:

$$k = \left(\frac{\sigma}{v_m}\right)^{-1.086} \tag{5}$$

$$c = \frac{v_m}{\Gamma(1+\frac{1}{k})} \tag{6}$$

The  $k$  and  $c$  parameters of the Weibull function are defined in terms of the gamma function ( $\Gamma$ ) as follows:

$$v_m = \frac{1}{n} \sum_{i=1}^n v_i \tag{7}$$

$$\sigma^2 = \frac{1}{n-1} \sum_{i=1}^n (v_i - v_m)^2 \tag{8}$$

$$\Gamma(X) = \int_0^\infty t^{X-1} \cdot e^{-t} dt \tag{9}$$

### 2.3 Probable and maximum wind speed

Two significant wind speeds for energy estimation derived from the scale and shape factors are the most probable wind speed ( $V_{mpb}$ ) and the wind speed carrying the maximum energy ( $V_{MaxE}$ ), as expressed in Equations 10 and 11 as in [19]:

$$V_{mpb} = c \left(\frac{k-1}{k}\right)^{1/k} \tag{10}$$

$$V_{MaxE} = c \left(\frac{k+2}{k}\right)^{1/k} \tag{11}$$

### 2.4 Wind power density Estimation

Wind energy density is valuable metric for assessing the wind resources available at a given height above the ground level, as it indicates the quantity of energy that will be able to be converted by a wind turbine [20]. The accessible energy within the flowing wind at an average velocity  $v_m$  via a wind rotor blade possessing a swept area  $A$  in  $m^2$  at any given location can be estimated as:

$$P(v) = \frac{\rho A v_m^3}{2} \tag{12}$$

The wind power per unit area is expressed as:

$$P(v) = \frac{\rho v_m^3}{2} \tag{13}$$

The wind energy density utilizing the Weibull probability density function can be computed using the provided equation in [21, 22] as:

$$P(v) = \frac{p(v)}{A} \tag{14}$$

$$\frac{p(v)}{A} = \frac{\rho c^3 \Gamma}{2} \cdot \left(\frac{v}{c}\right)^{k+1} \tag{15}$$

Where  $P(v)$  represents the wind power ( $W$ ),  $p(v)$  is the wind power density ( $W/m^2$ ),  $\rho$  denotes the air density at the site ( $1.21 \text{ kg/m}^3$ ),  $A$  is rotor's blade sweep area ( $m^2$ ), and  $\Gamma(x)$  is the gamma function of  $x$ .

### 2.5 Wind Speed Extrapolation

Wind speed variability is influenced by both the distance above the ground and the roughness characteristics of the terrain. Therefore, a technique is required to estimate wind speed at a certain height based on the measured speed at a different vertical level. The Power Law, often used to describe the variation in wind speed at different hub heights, is given by [20]:

$$\frac{V_2}{V_1} = \left(\frac{h_2}{h_1}\right)^\alpha \tag{16}$$

Where  $V_2$  is the wind velocity at the estimated height  $h_2$  and  $V_1$  is the original wind velocity at the height  $h_1$  while  $\alpha$  is the surface characteristic roughness given in Equation 17 and it ranges from 0.05 to 0.5 based on the nature of the location.

$$\alpha = \frac{0.37 - 0.088 \ln V_1}{1 - 0.088 \ln \left(\frac{h_1}{10}\right)} \tag{17}$$

## 3. Findings and Analysis

This section presents the annual and monthly changes in wind velocity characteristics for the Kusada community.

### 3.1 Yearly and monthly average wind speeds

Tables 1 and 2 present the monthly wind characteristics for the Kusada community at a height of 10 m. From these tables, it can be observed that the minimum monthly average wind velocity in this site is 1.65 m/s in August, and the maximum occurs in January at 3.34 m/s. Table 2 further indicates that the monthly minimum values for  $V_{maxE}$  and  $V_{mpb}$  are 1.8008 m/s and 3.9268 m/s in month of September and December respectively. Additionally, Tables 1 and 2 present the results for wind power density at an altitude of 10 m in Kusada community, as calculated using Equations (12) to (15).

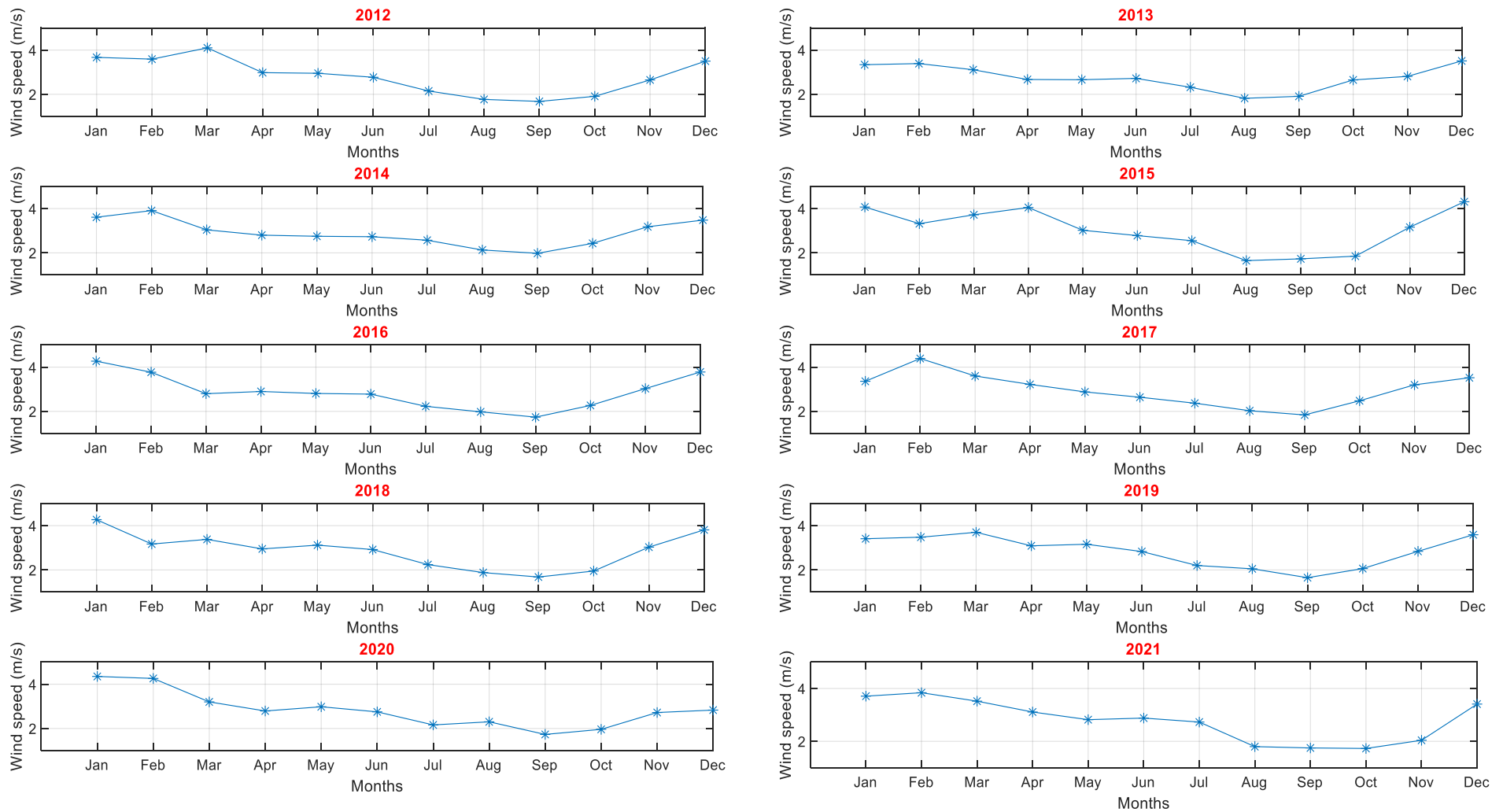


Figure 2: 10 years Wind speed of Kusada community in Katsina state

Table 1: Monthly variation of wind characteristics of kusada community

| Period | $V_{min}$<br>(m/s) | $V_{Max}$<br>(m/s) | $V_m$<br>(m/s) | $k$     | $c$<br>(m/s) | $PD$<br>( $w/m^2$ ) | $RMSE$    | $R^2$   |
|--------|--------------------|--------------------|----------------|---------|--------------|---------------------|-----------|---------|
| Jan.   | 3.34               | 4.35               | 3.7891         | 11.1901 | 3.9598       | 37.6846             | 0.0044379 | 1.0004  |
| Feb.   | 3.17               | 4.39               | 3.7273         | 10.7821 | 3.8965       | 35.87               | 0.010294  | 0.97846 |
| Mar.   | 2.8                | 4.1                | 3.4145         | 10.394  | 3.5741       | 27.5776             | 0.0010829 | 1.0028  |
| Apr.   | 2.67               | 4.05               | 3.0291         | 7.1225  | 3.2016       | 19.2529             | 0.0062767 | 0.97263 |
| May    | 2.66               | 3.16               | 2.9036         | 20.5822 | 2.9761       | 16.9584             | 0.0095046 | 0.96724 |
| Jun.   | 2.59               | 2.92               | 2.7627         | 33.2363 | 2.8064       | 14.6074             | 0.0072783 | 1.0558  |
| Jul.   | 2.15               | 2.73               | 2.3709         | 12.8798 | 2.4619       | 9.2322              | 0.005662  | 1.0036  |
| Aug.   | 1.65               | 2.3                | 1.9545         | 11.5815 | 2.0378       | 5.1724              | 0.0033818 | 1.0275  |
| Sept.  | 1.62               | 1.98               | 1.7555         | 15.6887 | 1.8084       | 3.7474              | 0.014313  | 0.89574 |
| Oct.   | 1.73               | 2.65               | 2.1355         | 8.1099  | 2.2615       | 6.7457              | 0.0064043 | 0.99115 |
| Nov.   | 2.04               | 3.2                | 2.8736         | 13.2014 | 2.999        | 16.4382             | 0.0033075 | 1.0183  |
| Dec.   | 2.83               | 4.31               | 3.5982         | 10.9904 | 3.7532       | 32.2707             | 0.0017068 | 1.0013  |
| Yearly | 2.74               | 3.02               | 2.8564         | 35.7795 | 2.8945       | 16.1435             | 0.0088111 | 1.0602  |

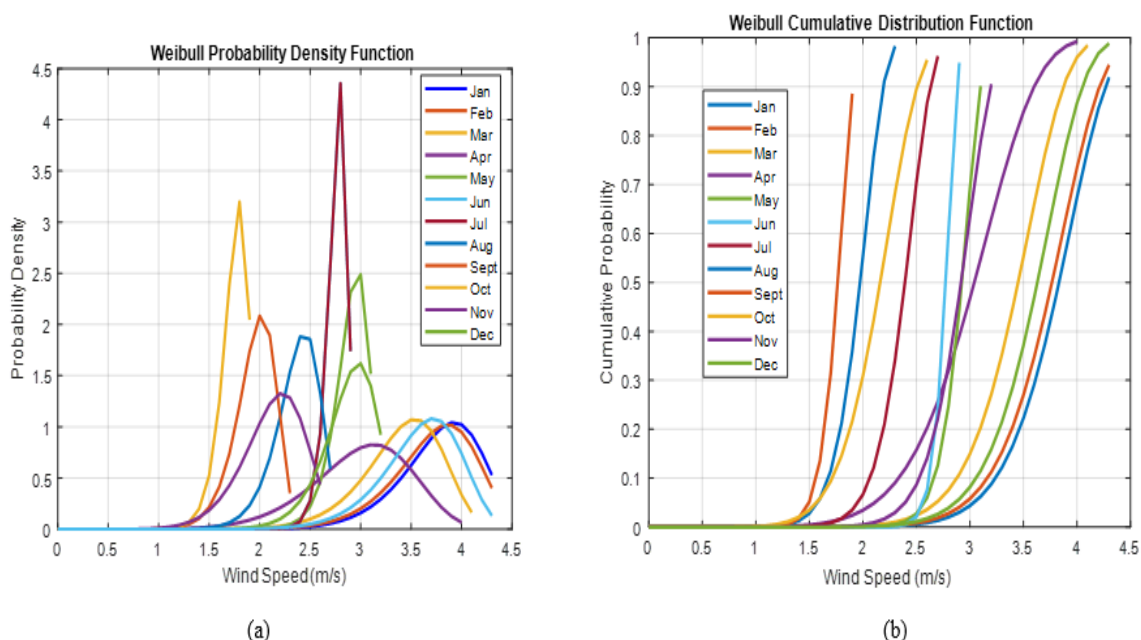


Figure 3: Wind speed on a monthly basis for Kusada Community (a) Probability density function and (b) Cumulative distribution functions

Table 2: Most probable wind speed

| Period | $V_{mpb}$ | $V_{MaxE}$ | $k$     | $c$    | Power<br>( $w/m^2$ ) |
|--------|-----------|------------|---------|--------|----------------------|
| Jan.   | 3.9268    | 4.0184     | 11.1901 | 3.9598 | 37.6846              |
| Feb.   | 3.8615    | 3.9585     | 10.7821 | 3.8965 | 35.87                |
| Mar.   | 3.5395    | 3.6351     | 10.394  | 3.5741 | 27.5776              |
| Apr.   | 3.1343    | 3.3148     | 7.1225  | 3.2016 | 19.2529              |
| May    | 2.9689    | 2.9895     | 20.5822 | 2.9761 | 16.9584              |
| Jun.   | 2.8038    | 2.8113     | 33.2363 | 2.8064 | 14.6074              |
| Jul.   | 2.4465    | 2.4896     | 12.8798 | 2.4619 | 9.2322               |
| Aug.   | 2.022     | 2.066      | 11.5815 | 2.0378 | 5.1724               |
| Sept.  | 1.8008    | 1.8223     | 15.6887 | 1.8084 | 3.7474               |
| Oct.   | 2.2251    | 2.3238     | 8.1099  | 2.2615 | 6.7457               |
| Nov.   | 2.9812    | 3.0312     | 13.2014 | 2.999  | 16.4382              |
| Dec.   | 3.7208    | 3.8107     | 10.9904 | 3.7532 | 32.2707              |
| Yearly | 2.8922    | 2.8989     | 35.7795 | 2.8945 | 16.1435              |

The average monthly power densities at the location mirror the pattern observed in the average wind velocity. The monthly average pd in the site varies from 3.75 in September to 37.68  $W/m^2$  in January. According to the wind power classification scheme developed by the Pacific

Northwest Laboratory (PNL) [23], Kusada community falls within the Class 1 wind resource classification, characterized by a pd of less than 100  $W/m^2$  throughout the year.

The monthly  $k$  and  $c$  parameters, computed analytically from the available wind speed using Equations (5) and (6), are shown in Tables 1 and 2. The  $c$  parameter ranges from 1.8084 in September to 3.9598 m/s in January, while the  $k$  parameter varies from 7.1225 in April to 33.2363 in June for the Kusada community. Table 1 also presents the annual wind speed characteristics for the region. It shows that the yearly average wind velocity is 2.74 m/s, and the annual average power density is 16.1435  $W/m^2$ . The yearly pd is below 100  $W/m^2$ , placing this location in the northern part of Nigeria under the Class 1 wind energy resource (WER) category. This WER category is typically not suitable for the installation of large-scale wind turbines but may be suitable for small, independent systems such as charging batteries and mechanical uses such as pumping water. Additionally, the energy in this location can be utilized

in combined energy forms, such as combinations of wind with solar, battery, and diesel generator technologies.

### 3.2 Weibull frequency distributions

The Weibull monthly probability density and cumulative distributions for Kusada community, based on the complete year time series data, are illustrated in Figure 3. It shows that the curves for the entire year are quite similar at this location. It is also observed that wind speeds rarely exceed 4.5 m/s in some months throughout the year. Table 1 presents the statistical error metrics used to evaluate the fit of the data. The Root Mean Square Error (RMSE) values range from a minimum of 0.0010829 to a maximum of 0.010294, both of which are very close to zero, indicating an excellent fit. Additionally, the coefficient of determination ( $R^2$ ) values ranges from 0.89574 to 1.00558, with values close to 1 further confirming the high accuracy of the fit.

## 4 Conclusion

Based on the statistical data, wind energy potential computations, and performance assessments conducted for Kusada community in Katsina State, the following conclusions were drawn from the study:

- a. In Kusada community, the monthly mean wind velocity ranges from a minimum of 1.73 in October to a maximum of 3.34 m/s in January. The monthly mean pd varies from 3.74 in the month of September to 37.68 W/m<sup>2</sup> in the month of January. As the pd remains below 100 W/m<sup>2</sup> throughout the year, the community falls under Class 1 wind resource classification.
- b. The c parameter ranges from 1.8084 in September to 3.9598 m/s in January, while the k parameter varies from 7.1225 in April to 33.2363 in June.
- c. The wind energy in the Kusada community is better suited for small, self-contained energy systems and mechanical uses, such as pumping of water and battery charging. Additionally, it can be integrated into hybrid energy forms, such as those combining wind with solar, battery storage, and diesel generators.

## Reference

- [1]. Thiaw, L., Sow, G., Fall, S. S., Kasse, M., Sylla, E. and Thioye, S., (2010). A neural network based approach for wind resource and wind generators production assessment, *Applied Energy*, 87(5), 1744-1748.
- [2]. Bonamini, G., (2012). Exergy and process analysis to assess primary energy resource consumption: a critical review, *politesi*, 1, 125-150.
- [3]. Dénes, D. L., Csilla, M., Kosmaczewska, J., Gyula, F., Martin, Z., Imre, V. and Palenčíková, Z., (2019). Ecoenergy tourism, study into some aspects of relationship between use of renewable energy resources and sustainable regional and rural development, *DSPACE*, 18, (100)27.
- [4]. De Vita, L. L., (2022). Make me dictator and I will save humankind. A rational approach to the emergency of the 21st century, *Central European Review of Economics and Management (CEREM)*, 6(1), 67-93.
- [5]. Panos, E., Densing, M., and Volkart, K. (2016). Access to electricity in the World Energy Council's global energy scenarios: An outlook for developing regions until 2030, *Energy Strategy Reviews*, 9, 28-49.
- [6]. Bazilian, M., Nussbaumer, P., Rogner, H. H., Brew-Hammond, A., Foster, V., Pachauri, S., ... and Kammen, D. M. (2012). Energy access scenarios to 2030 for the power sector in sub-Saharan Africa. *Utilities Policy*, 20(1), 1-16.
- [7]. Shaaban, M., and Petinrin, J. O. (2014). Renewable energy potentials in Nigeria: Meeting rural energy needs, *Renewable and Sustainable Energy Reviews*, 29, 72-84.
- [8]. Reader, G. T., (2021). Developing Remote Communities: Access to Electricity. Engineering for Sustainable Development and Living: Preserving a Future for the Next Generation to Cherish, *Brown Walker Press*, 2, 29-31.
- [9]. Oyedepo, S. O., (2012). Energy and sustainable development in Nigeria: the way forward. *Energy, Sustainability and Society*, 2, 1-17.
- [10]. Mudakkar, S. R., Zaman, K., Khan, M. M. and Ahmad, M., (2013). Energy for economic growth, industrialization, environment and natural resources: living with just enough. *Renewable and Sustainable Energy Reviews*, 25, 580-595.
- [11]. El-Mazariky, A., (2011). Long-Term Statistical Analysis and Operational Studies of Wind Generation Penetration in the Ontario Power System (Master's thesis), University of Waterloo.
- [12]. Akorede, M. F., Ibrahim, O., Amuda, S. A., Otuoze, A. O. and Olufeagba, B. J., (2017). Current status and outlook of renewable energy development in Nigeria. *Nigerian Journal of Technology*, 36(1), 196-212.
- [13]. Rediske, G., Burin, H. P., Rigo, P. D., Rosa, C. B., Michels, L. and Siluk, J. C. M., (2021). Wind power plant site selection: A systematic review. *Renewable and Sustainable Energy Reviews*, 148, 111293.
- [14]. Marugán, A. P., Márquez, F. P. G., Perez, J. M. P. and Ruiz-Hernández, D., (2018). A survey of artificial neural network in wind energy systems. *Applied Energy*, 228, 1822-1836.
- [15]. Chaudhuri, A., Datta, R., Kumar, M. P., Davim, J. P. and Pramanik, S., (2022). Energy conversion strategies for wind energy system: Electrical, mechanical and material aspects. *Materials*, 15(3), 1232.
- [16]. Hoxha, B., Selimaj, R., and Osmanaj, S., (2018). An experimental study of Weibull and Rayleigh distribution functions of wind speeds in Kosovo. *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, 16(5), 2451-2457.
- [17]. Wais, P., (2017). A review of Weibull functions in wind sector. *Renewable and Sustainable Energy Reviews*, 70, 1099-1107.
- [18]. Mouangue, R. M., Kazet, M. Y., Kuitche, A. and Ndjaka, J. M., (2014). Influence of the determination

- methods of K and C parameters on the ability of Weibull distribution to suitably estimate wind potential and electric energy. *International Journal of Renewable Energy Development*, 3(2), 145-150.
- [19]. Adaramola, M. S., Oyewola, O. M., Ohunakin, O. S. and Akinnawonu, O. O., (2014). Performance evaluation of wind turbines for energy generation in Niger Delta, Nigeria. *Sustainable Energy Technologies and Assessments*, 6, 75-85.
- [20]. Ayodele, T. R., Ogunjuyigbe, A. S. O. and Amusan, T. O., (2016). Wind power utilization assessment and economic analysis of wind turbines across fifteen locations in the six geographical zones of Nigeria. *Journal of Cleaner Production*, 129, 341-349.
- [21]. Miller, L. M., and Keith, D. W. (2018). Observation-based solar and wind power capacity factors and power densities. *Environmental Research Letters*, 13(10), 104008.
- [22]. Masseran, N., Razali, A. M., and Ibrahim, K. (2012). An analysis of wind power density derived from several wind speed density functions: The regional assessment on wind power in Malaysia. *Renewable and Sustainable Energy Reviews*, 16(8), 6476-6487.
- [23]. Celik, A. N. (2007). A techno-economic analysis of wind energy in southern Turkey. *International Journal of Green Energy*, 4(3), 233-247.