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ORIGINAL RESEARCH ARTICLE

WIND RESOURCE ASSESSMENT AND ENERGY POTENTIAL FOR INSTITUTIONAL ELECTRICITY GENERATION AT FEDERAL UNIVERSITY OF TECHNOLOGY AKURE

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ABSTRACT

There are challenges in providing sufficient power supply in Nigerian universities as it often leads to disruption in learning processes. Therefore, alternative energy sources such as renewable sources need to be studied. This study focused on assessing the availability of wind energy and its potential for power generation at the Federal University of Technology, Akure (FUTA), Ondo State, Nigeria. The availability of wind was done through wind speed measurements using a calibrated anemometer mounted on a 10 m mast, along with an Onset HOBO U30 Data Logger, which recorded wind speed for 8,760 hours for the whole year 2024. The measured wind speeds were extrapolated to 30 m, 50 m, and 100 m hub heights using the power law equation for the atmospheric boundary layer, where the wind shear exponent is set as α=0.20, considering the roughness nature of the study area. The wind climate was statistically modeled through the use of the Weibull probability distribution model using a shape factor of k = 2, an estimation based on both the empirical observations and previous wind studies in south-western Nigeria. The Weibull scale parameter increased from c = 5.08 m/s at 10 m to c = 8.05 m/s at 100 m with the goodness of fit statistics indicating R^2 of 0.5561 and RMSE reducing from 0.0707 to 0.0446 confirming that the model worked satisfactorily at all hub heights considered. Annual mean wind speed climbed from $4.50\,m/s$ at $10\,m$ to $7.13\,m/s$ at $100\,m$, a rise of roughly 58%. Correspondingly, wind power density grew from $69.7\,W/m^2$ at $10\,m$ (a low-resource classification) to $277.6\,W/m^2$ at $100\,m$ (bordering on a moderate-resource classification), while annual wind energy density quadrupled, moving from about $610.9\,kWh/m^2/year$ to approximately $2{,}432\,kWh/m^2/year$ over the same range. Annual energy production (AEP) at each hub height was obtained by combining the site-specific Weibull probability density function with representative turbine power curves. The results showed that FUTA holds a wind resource that is technically usable from $50\,m$ upward, making the site suitable for small- to medium-scale variable-speed turbines. Harnessing this resource could meaningfully cut the institution's reliance on diesel generators, reduce running costs, and support its broader sustainability goals. The study provided a quantitative basis for follow up techno-economic feasibility work, turbine selection, and the design of a wind-solar hybrid system at FUTA.

1.0 Introduction

Access to energy is key to economic growth, technological progress and social development. Steady electricity is very critical for universities and other educational institutions, where laboratory, Information Technonology (IT), research facilities, teaching areas and daily operations are heavily reliant on it. However, in many parts of the developing world, power supply remains inconsistent, often constrained by ageing infrastructure in the electricity grid, low generation capacity, network constraints, and growing demand, all of which have a negative impact on education and economic development (International Energy Agency [IEA], 2024; World Bank, 2022). This is well illustrated in the power sector of Nigeria where despite several rounds of reform and investment, generation and distribution issues remain and particularly universities continue to have a frequent experience of power outages that hinder teaching and research (Energy Commission of Nigeria [ECN], 2015; World Bank, 2022; Dare, 2025).

FUTA in the state of Ondo is presently powered mostly by grid power and diesel generators. The cost of this setup is high and it contributes to environmental pollution and greenhouse gas emissions (ECN, 2015; International Renewable Energy Agency [IRENA], 2022). Renewable technologies offer a means to enhance the reliability of supply and reduce environmental impacts, and wind energy is one of those technologies that is both technically mature and offers environmental benefits and potential cost competitiveness (IRENA, 2023). The world's installed wind power has grown at a fast pace in the last two decades, and currently contributes significantly to electricity production in many countries (Global Wind Energy Council [GWEC], 2021).

The operating principle of wind energy systems involves capturing the kinetic energy of moving air and transforming it into mechanical rotational energy, which is subsequently converted into electrical power through a Wind Energy Conversion System (WECS). The rotor extracts energy from the wind flow and rotates a generator, generating electricity to be supplied to the power grid or to power off-grid applications (Mostafa *et al*., 2023; Hannan *et al*., 2023). Local conditions, wind speed distribution, power density, seasonal variation and long-term wind behavior are all important factors that influence wind performance at a specific site and the technical and economic viability of a wind project (Jung, 2024; Wimhurst *et al*., 2023). The wind resources in Nigeria are not homogeneous; moderate wind resources are found in other parts of the country and can be harnessed, if the appropriate wind turbine technology is selected, for small and medium-scale applications, while strong wind resources can be found in the north and coastal regions of Nigeria due to more favourable atmospheric conditions.

The assessment of wind resource at a site requires a thorough analysis of data along with the use of statistical tools that can accurately represent wind-speed behaviour, such as mean wind speed, power density, and probability distribution functions (Abubakr *et al*., 2022; Hernández-Meléndez *et al*., 2024). The most generally used distribution used to represent wind-speed frequency is the Weibull distribution, which is flexible enough to fit a variety of wind regimes (Wilks, 2019). It provides a statistically sound representation of the wind speed distribution at a site, thus helping to inform energy-potential assessments and turbine selection decisions for a site (Oyedepo *et al*., 2012; Serban *et al*., 2020).

In this background, the present study will aim to study the wind resources potential of FUTA through an analysis of wind data measured with the appropriate statistical techniques. The aim was to provide quantitative data and information to determine the feasibility of introducing wind turbines for electricity generation at the university, and contribute to the goal of transitioning towards sustainable energy use in Nigerian academic institutions.

2. Materials and Method

2.1 Study Area

The research was done in the Federal University of Technology Akure (FUTA) located in Akure, Ondo State, Nigeria. The university lies roughly in between 7.30° N latitude and 5.13° E longitude as shown in Figure 1 below. The research region enjoys a tropical climate marked by clear wet and dry seasons with warm temperatures and wind conditions brought about by the interaction of air masses from the continent and the sea (NiMet, 2023). Its terrain is somewhat undulating and dotted with vegetation and buildings, features that affect surface roughness and turbulence and therefore need to be taken into account when assessing wind potential (Shi *et al*., 2021; Wimhurst *et al*., 2023).

2.2 Wind Data Acquisition

The main source of wind data included an anemometer mounted on a $10\ m$ tower and recorded using an Onset HOBO U30. In other to verify these measurements, additional data were obtained from FUTA's Department of Meteorology and compared against the measured dataset. In total, the dataset spanned one full calendar year (2024) with 8,760 hourly records, each capturing wind speed (m/s), wind direction (degrees), ambient temperature (°C), and atmospheric pressure (kPa).

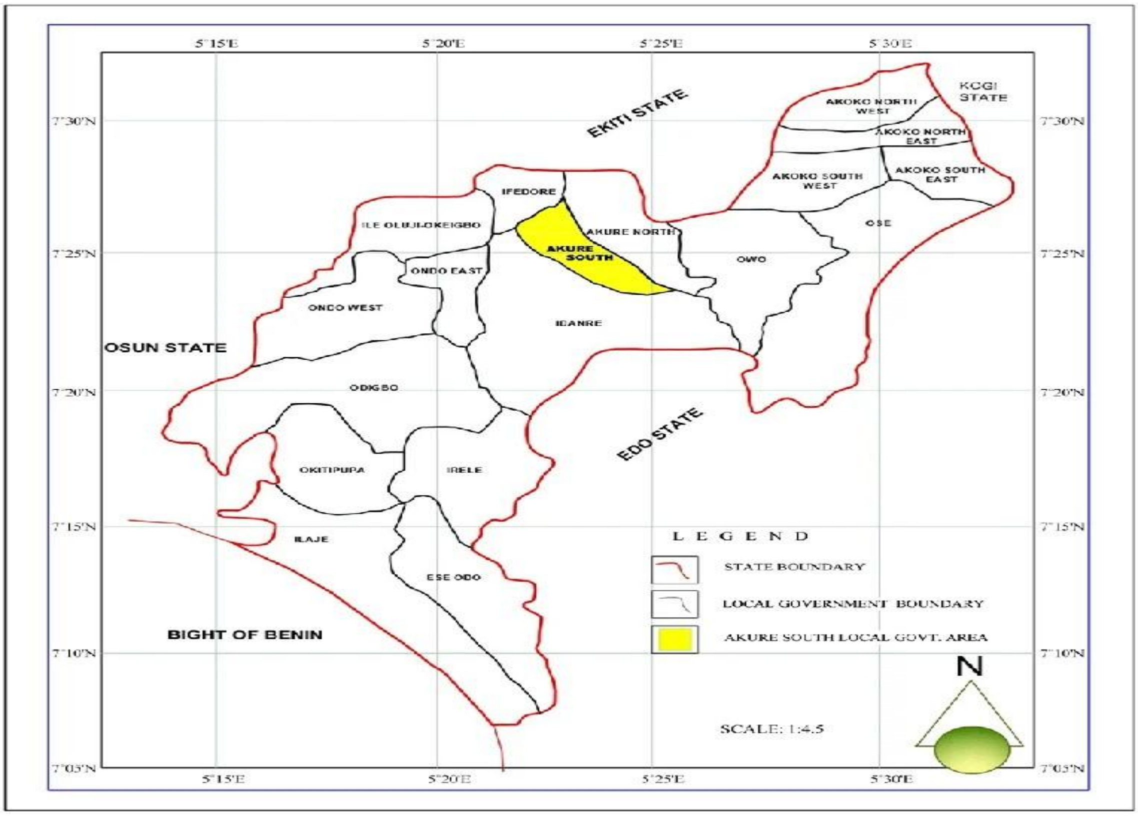

Figure 1: Map of Nigeria Showing the study area (Akinluyi *et al*., 2021)

Together, these variables made it possible to characterise the local wind regime and estimate the technical potential for wind power generation, supporting downstream decisions on turbine choice, expected yield, and overall project viability (Hannan *et al*., 2023; Serban *et al*., 2020). Table 1 gives a sample of the recorded data.

Table 1: Sample of Hourly Wind Dataset Collected at 10 m Hub Height

Date/Time	Wind Speed (m/s)	Wind Direction (deg)	Temperature (°C)	Pressure (kPa)
01/01/2024 12:00 am	4.198	209.1	28.97	101.286
01/01/2024 01:00 am	3.502	196.2	29.07	101.262
01/01/2024 02:00 am	4.065	184.3	26.45	101.235
01/01/2024 03:00 am	4.697	190.1	28.74	101.251
01/01/2024 04:00 am	2.961	189.5	23.47	101.214
01/01/2024 05:00 am	2.816	184.9	26.95	101.224
01/01/2024 06:00 am	4.324	195.1	24.53	101.218
01/01/2024 07:00 am	3.498	196.9	25.31	101.200

2.3 Data Pre-Processing and Quality Control

Before analysis, the dataset underwent through pre-processing to make sure that the data were correct and valid. It included removal of missing value, outliers, and verification of measurement consistency. Since commercial wind turbines are installed at hub heights much higher than that of regular meteorological measurement, it was necessary to extrapolated the wind speeds to those specific height of turbines. In this research, the speeds measured at *10 m* have been extrapolated to *30 m*, *50 m*, and *100 m* using the power law. a method commonly applied in wind-resource assessment and yield estimation (Jung, 2024). The power-law expression is given in Equation 1.

$$v = V_{ref}\left(\frac{H}{H_{ref}}\right)^{\alpha} \qquad 1$$

where v is the wind speed (m/s) above height H (m) above ground level, Vref is the wind speed (m/s) at reference height H_{ref} (m), and α is the exponent for wind shear, which varies between 0.1 on flat land to as high as 0.4 in urban area (Gualtieri, 2019; Shi *et al*., 2021). considering the fact that the study region has mixed usage of the land and irregular topography, exponent of $\alpha = 0.2$ was used for this study.

2.4 The Mean Wind Speed of Collected Data

Mean wind speed was obtained using the standard statistical formula shown in Equation 2, and Figure 2 presents the resulting average monthly wind speed.

$$\bar{v} = \frac{1}{N}\sum_{i=1}^{n} v_i \qquad 2$$

where $\bar{v}$ is the mean wind speed, N is the total number of data points (measurements) in the time period of interest and v_i is the wind speed measurement at i-th time step.

2.5 The Wind Power Density Model (WPD)

Wind power density (WPD) which is the amount of kinetic energy carried by the wind per unit of swept area, it was computed using Equation 3, and is a key parameter for judging how suitable a site is for wind energy generation and for comparing sites against one another (Gualtieri, 2019; Zhao and Xu, 2025).

$$WPD = \frac{1}{2}\rho\left(\frac{1}{N}\sum_{i=1}^{N} V_i^3\right) \qquad 3$$

where ρ is the air density in kg/m^3, typically around $1.225\ kg/m^3$ at the sea level and V is the wind speed in ms^{-1}. The power density is W/m^2 (watts per square meter). Figure 3 presents the WPD at each of hub height.

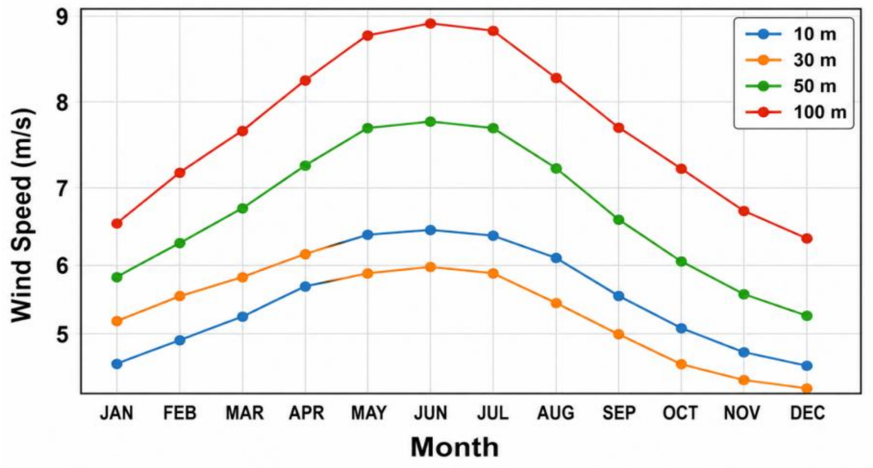

Figure 2: Average monthly wind speed at various hub heights

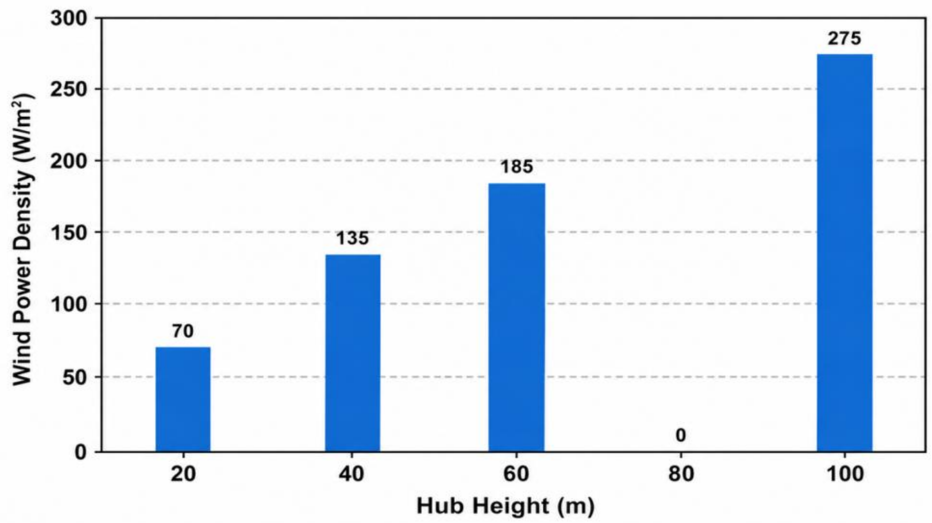

Figure 3: Wind power density at different hub heights

Weibull distribution offers a statistical picture of how often different wind speeds occur at a location, which is why it is so frequently used in wind-resource assessment, energy-yield estimation, and turbine performance studies (Shi *et al.*, 2021). Its probability density function is presented using Equation 5 and the cumulative distribution function (CDF) in Equation 6.

$$F(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}} \quad 5$$

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^{k}} \quad 6$$

where v is the wind speed (ms^{-1}), k is the shape parameter and it is dimensionless ranging $1 \leq k \leq 3$ for wind data and c the scale parameter (ms^{-1}).

The Weibull density function was applied to model wind speed distribution across all the four hub heights. Setting shape parameter at $k = 2$ reduced Equation 5 to the Rayleigh form given in Equation 7. This simplification is standard practice where detailed site-specific data are unavailable, since the Rayleigh distribution still gives a reasonably good approximation of wind behaviour in many locations (Hernández-Meléndez *et al*., 2024; Serban *et al*., 2020):

$$(v) = \frac{2v}{c^2} e^{-\left(\frac{v}{c}\right)^{2}} \quad 7$$

Table 2 sets out the resulting probability density models for each hub height using the calculated scale parameters with Figure 4 shows the plots for probability density function, and Figure 5 shows the cumulative distribution function.

Table 2: The Wind Probability Distribution Model

Hub Height (m)	Probability Density Model
10.00	$0.075ve^{-\left(\frac{v}{5.08}\right)^2}$
30.00	$0.0501ve^{-\left(\frac{v}{6.32}\right)^2}$
50.00	$0.0407ve^{-\left(\frac{v}{7.01}\right)^2}$
100.00	$0.0309ve^{-\left(\frac{v}{8.05}\right)^2}$

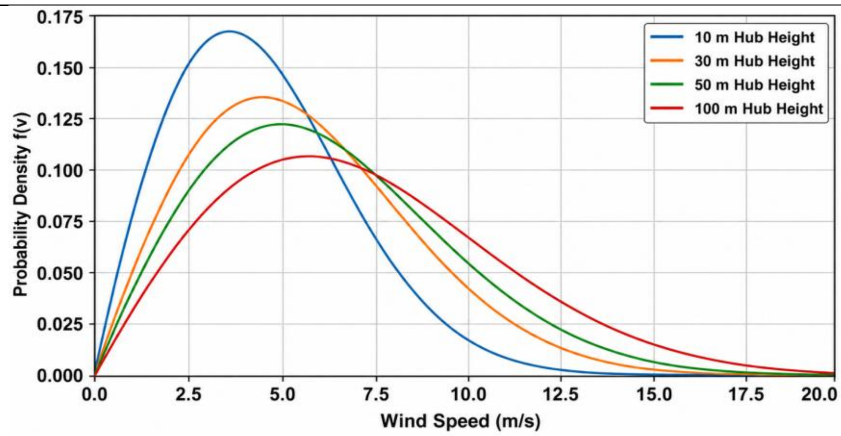

Figure 4: Probability Density Function for Wind Speed

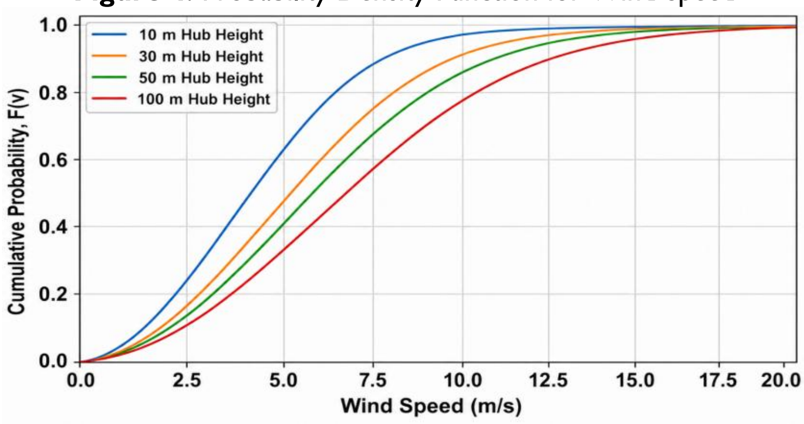

Figure 5: The Cumulative Distribution Function of the Model

2.6 Wind Energy Assessment Framework Adopted

Figure 6 sets out the overall framework followed in this study. The process started with wind data collection and pre-processing, moved through wind speed extrapolation and statistical modelling, and continued with wind power density and annual energy production calculations, before ending in a feasibility assessment and turbine selection for the site.

2.7 Annual Energy Production (AEP) Model

To estimate the expected energy yield of a turbine, the site's wind speed distribution was combined with a representative turbine power curve. A turbine's actual electrical output was not identical to the theoretical wind power density available at a site, since real generation depended on the turbine's own operating characteristics, principally its cut-in, rated speed, and cut-out speeds. This power-curve-based method, paired with a fitted wind-speed probability model, remained a standard way of estimating AEP and comparing turbine suitability at a given site (Hernández-Meléndez *et al*., 2024). The AEP calculation is given in Equation 9.

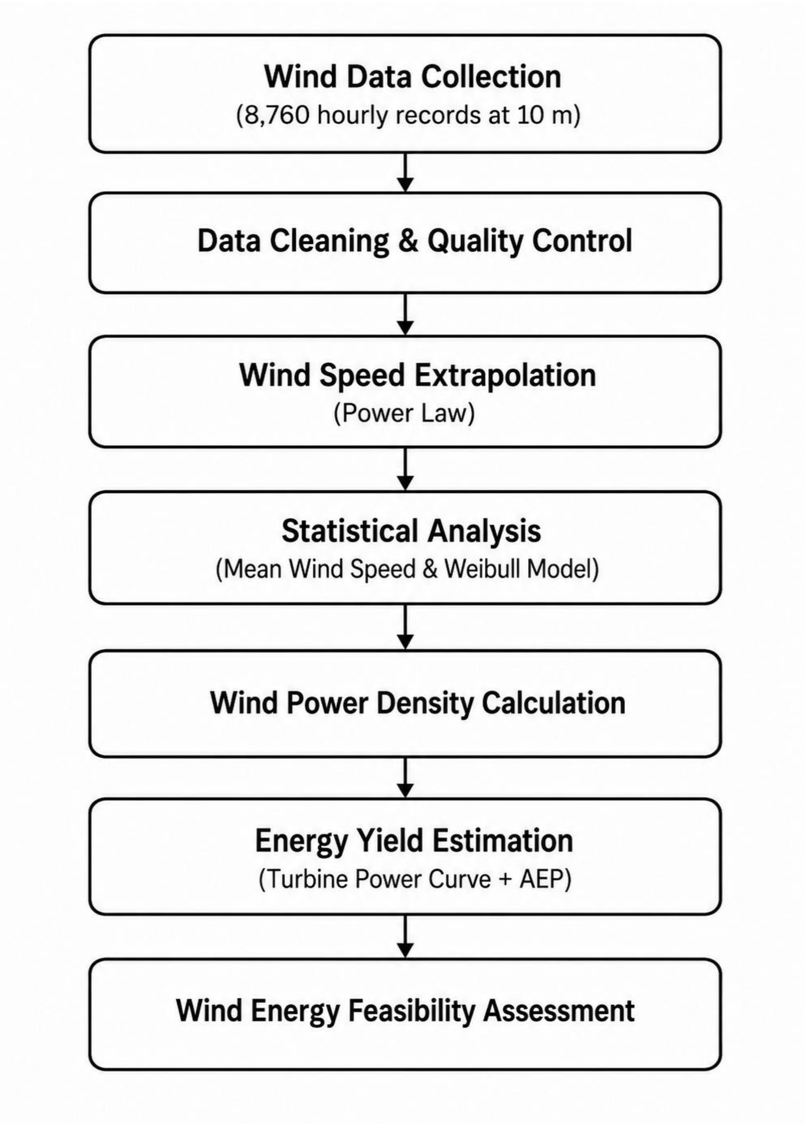

Figure 6: Wind Energy Assessment Framework

2.7 Annual Energy Production (AEP) Model

$$AEP = 8760 \int_0^\infty P_t(v) \frac{1}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^k} dv \quad 9$$

Where $P_t(v_i)$ is the turbine output power at wind speed v_i the AEP was modelled by pairing the turbine power curve with the site's Weibull probability density function at each hub height, as summarised in Table 3.

Table 3: The Annual Energy Production Model

Hub Height (m)	AEP Model
10.00	$8760\int_{0}^{\infty} p_t(v)0.075ve^{-\left(\frac{v}{5.08}\right)^2}dv$
30.00	$8760\int_{0}^{\infty} p_t(v)0.0501ve^{-\left(\frac{v}{8.32}\right)^2}dv$
50.00	$8760\int_{0}^{\infty} p_t(v)0.0407ve^{-\left(\frac{v}{7.01}\right)^2}dv$
100.00	$8760\int_{0}^{\infty} p_t(v)0.0309ve^{-\left(\frac{v}{8.05}\right)^2}dv$

3. Results and Discussion

3.1 Wind Speed Variation with Height

The wind speed profile indicated a positive correlation between wind speed and hub height, which is a typical observation in atmospheric boundary layer experiments. The near-surface friction created natural and man-made obstructions, like plants, buildings and undulating topography, decreased wind speed in lower altitudes; however, this friction effect decreased with altitude, allowing wind speed to increase. Mean wind speed at 10 m height was 4.50 m/s. Extrapolation using the power-law equation gave 5.61 m/s at 30 m, 6.21 m/s at 50 m and 7.13 m/s at 100 m, with a total increase of 58% from 10 m to 100 m. Wind energy is proportional to the cube of wind speed, making this increase in wind speed very significant. These observations point out the significance of choosing the right hub height in wind energy system design, as shown in Figure 7 below.

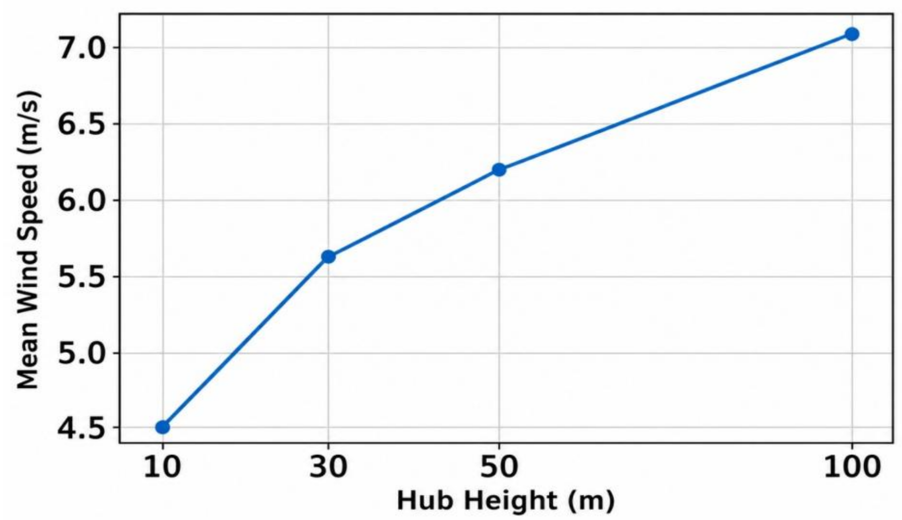

Figure 7: Mean Wind Speed Variation with Hub Height

The upward trend confirms that greater elevation offers more favourable wind conditions for power generation.

3.2 Wind Speed Frequency Distribution

The frequency distribution of wind speeds provided additional insight into the wind regime at the study area. Wind speed frequency analysis as shown in Figure 8 showed how often particular wind speed ranges occurred during the measurement period.

A large proportion of the observed wind speeds fell within the 3 to 7 $ms-1$ range, indicating that moderate wind speeds dominated the study area. This wind regime is typical of many tropical inland locations and suggests that wind turbines designed for low to moderate wind speed environments would be most suitable. Therefore, the presence of wind speeds within this range also means that turbines with lower cut-in speeds would be capable of generating electricity for a significant portion of the year at $50\ m$ to $100\ m$ hub height.

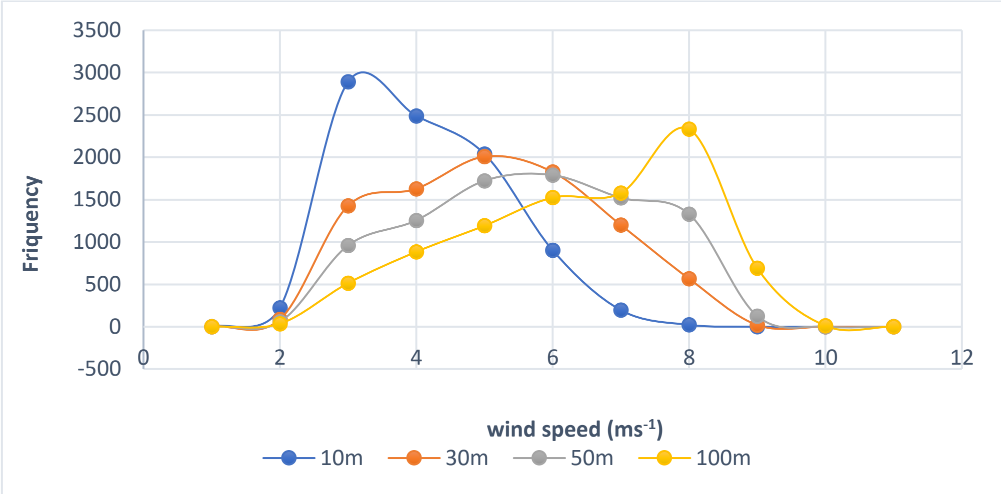

Figure 8: Wind speed annual frequency distribution

3.3 Weibull Probability Distribution Analysis

The statistical characteristics of the wind resource have been analyzed using the Weibull distribution, as discussed above, which is the probability distribution of wind speeds, commonly used in wind resource analysis as shown in Table 4. The probability density function for all four hub heights have been plotted in Figure 9 this showed the peak of distribution shifts toward higher wind speeds with increase in height, confirming that stronger winds became more common at greater elevations.

Table 4: Weibull Distribution Parameters and Goodness-of-Fit Statistics ($k = 2$, Rayleigh Distribution).

Hub Height (m)	Mean Wind Speed (m/s)	Shape Parameter k	Scale Parameter c (m/s)	R^2	RMSE
10	4.50	2.00	5.08	0.5561	0.0707
30	5.61	2.00	6.32	0.5561	0.0568
50	6.21	2.00	7.01	0.5561	0.0513
100	7.13	2.00	8.05	0.5561	0.0446

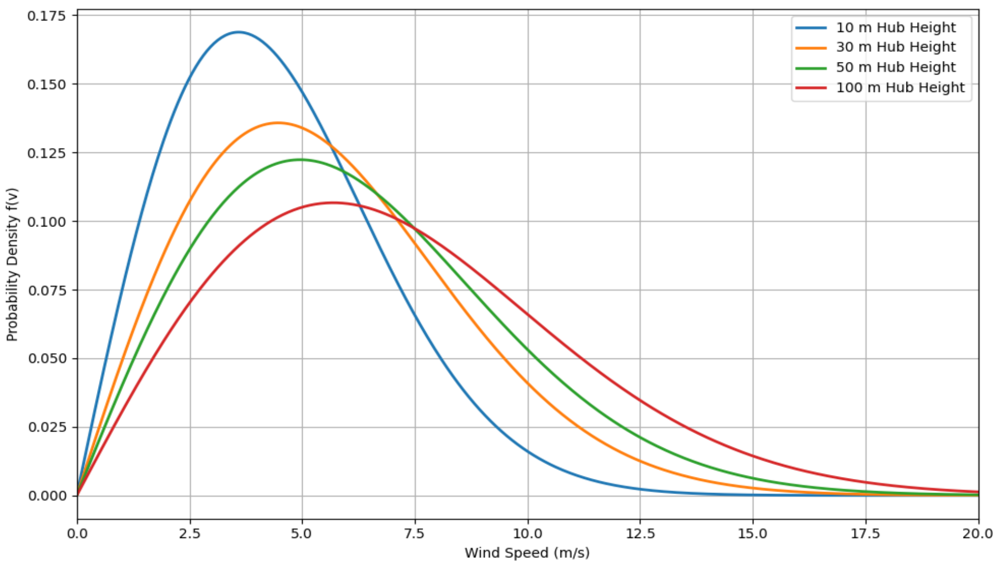

Figure 9: Weibull Probability Density Curves for Different Hub Heights

The curves also indicated a rising probability of wind speeds exceeding typical turbine cut-in thresholds as height increased, which improved the energy-production outlook for turbines mounted higher up. The growth in the Weibull scale parameter with height reinforced this, confirming that characteristic wind speed strengthened at greater elevations.

3.4 Wind Power Density Analysis

Wind power density was computed to quantify the kinetic energy carried by the wind at each hub height, an important measure of wind energy potential since it captured how much power passes through a given cross-sectional area of the airstream. The results showed a clear rise with height: 69.7 W/m^2 at 10 m (low-resource category), 134.8 W/m^2 at 30 m, 183.2 W/m^2 at 50 m, and **277.6** W/m² at 100 m, for the last which fell into the moderate resource category under standard classification schemes as represented in Figure 10 (Komolafe *et al*., 2024).

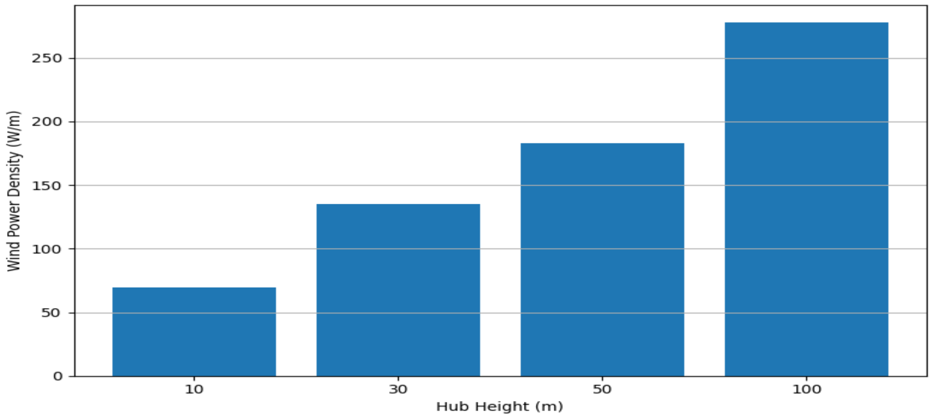

Figure 10: Wind power density at $10\ m, 30\ m, 50\ m, 100\ m$

This was a significant increase in power density with height which confirmed that mounting turbines higher substantially improved the wind resource available for capture.

3.5 The Annual Energy Production

Annual wind energy density (AWPD) base on the WPD values increased with height, rising from approximately 610.9 $kWh/m^2/year$ at 10 m to approximately 2,432 $kWh/m^2/year$ at 100 m, a factor four increase in the availability of wind energy improved at greater hub heights.

3.6 Implications for Wind Turbine Deployment

The wind speed analysis and Weibull modelling combined with power-density results gave a clear picture of wind energy's feasibility at FUTA. Wind speeds below 30 m were relatively low for the output that turbine could produce electricity and these turbines would probably only suitable for small stand-alone installations.

The installation improved markedly above 50 m, however, at 100 m, mean wind speed of 7.13 m/s sits comfortably within operating range of many modern turbines built for moderate wind regimes and machines that typically combine low cut-in speeds with aerodynamic designs optimised for efficient generation even in moderate conditions. Combining the wind-speed probability distribution with turbine power curves suggested that turbines installed between 80 m and 100 m could make a meaningful contribution to the university's electricity needs.

4. Conclusion

The wind energy potential assessment of FUTA with **8,760** hourly wind data (10 m hub height) for the 2024 calendar year. The values of these measurements were extrapolated to 30 m, 50 m, and 100 m using the power-law model $\alpha = 0.20$ and the wind regime was statistically characterised with a Weibull distribution model with $k = 2$.

The increase of the hub height from 10 m to 100 m, the mean wind speed increased from 4.50 ms^{-1} to 7.13 ms^{-1}, which is about 58% increase. The Weibull scale parameter increased from $c = 5.08\ ms^{-1}$ to $c = 8.05\ ms^{-1}$ over the same range and with a coefficient of determination (COD) of $R^2 = 0.5561$ and $RMSE$ values falling from 0.0707 to 0.0446, indicating an acceptable model fit at every hub height. Wind power density increased from 69.7 Wm^{-2} at 10 m (low-resource) to 277.6 Wm^{-2} at 100 m (approaching moderate-resource), while annual wind energy density quadrupled, from roughly $\sim 610.9\ kWh/m^2/year$ to $2{,}432\ kWh/m^2/year$.

These findings confirmed that FUTA has a technically exploitable wind resource from $50\ m$ upward, which is suited for small and medium scale wind turbines deployment. The integration of wind energy into the university's power grid will help mitigate reliance on diesel generators, reduce operational costs, and contribute to the university's sustainable energy goals.

Several points of limitations of the present analysis should be noted. The moderate coefficient of determination ($R^2 = 0.5561$) reflected the simplifying assumption of a fixed Weibull shape parameter (k = 2, the Rayleigh special case) rather than a shape parameter fitted directly to the measured data, and the assessment was on a single calendar year (2024) only, which cannot account for inter-annual variability in the local wind regime, directly estimate the Weibull shape and scale parameters from site wind speed measurements rather using the Rayleigh approximation, and conduct a comprehensive techno-economic feasibility study that compares turbine models, tower costs, installation cost and payback period. As per the study area wind-solar hybrid feasibility assessment is recommended which will complement wind and solar energy throughout the year. To take first step toward FUTA's reliance on grid electricity and diesel generation, the university management should consider a pilot-scale wind installation in the 80 m to 100 m hub height range where the result shows that the wind speed and energy yield is most favourable.

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