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Integration of Wind Power for Sustainable Energy at Lagos State University of Science and Technology: A Feasibility Study

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Abstract— This study investigates the feasibility of integrating wind power generation at Lagos State University of Science and Technology, specifically within the Mechanical Engineering Department, to address persistent electricity supply challenges in Nigeria. The research focuses on applying a five-bladed horizontal axis wind turbine (HAWT). It emphasises the urgent need for sustainable energy solutions due to the depletion of conventional sources and the environmental impact of fossil-fuel-powered generators. The methodology involves mathematical modeling to analyse wind shear exponent, Weibull distribution, maximum power available, and capacity factor. Utilising the FZ-3000 five-bladed HAWT, data is collected using a wireless wind anemometer.

The results reveal a calculated wind shear exponent aligned with terrain characteristics, emphasising the impact of obstructions on wind speed. Analysis of average wind speed throughout the day demonstrates the potential for continuous power generation at the Mechanical Engineering Department of the Lagos State University of Science and Technology. Examination of wind speed at different heights underscores the significance of elevated turbine towers for capturing higher wind speeds and optimising power output in the specific context of Lagos State University of Science and Technology. The calculated capacity factor of 44.17% suggests the viability of large wind turbine installations within the Mechanical Engineering Department, with room for improvement through routine maintenance.

This research contributes valuable insights into harnessing wind power at Lagos State University of Science and Technology, particularly within the Mechanical Engineering Department, addressing technical and environmental challenges for sustainable energy development. The study location, situated at coordinates Latitude of 6.6145° N and Longitude of 3.5375° E, provides a representative environment for assessing wind power potential in the region.

Keywords—*wind power, energy transition, sustainable energy, renewable energy, electricity generation*

1 Introduction

Like many developing nations, Nigeria grapples with a growing demand for electricity amid challenges in the conventional energy sector. Lagos State University of Science and Technology, a prominent educational institution in Nigeria, faces similar hurdles, relying predominantly on conventional power sources, including fossil fuel-driven generators [1]. This reliance poses economic challenges and raises environmental concerns due to the associated emissions of harmful gases [2] [3].

In response to the escalating need for sustainable and eco-friendly energy alternatives, this study seeks to explore the feasibility of wind power generation within the confines of Lagos State University of Science and Technology, with a specific focus on the Mechanical Engineering Department. The introduction outlines the institution's pressing issues, emphasising the imperative for a transition towards renewable energy sources. The study underscores the potential of wind energy, mainly by deploying a cutting-edge five-bladed horizontal axis wind turbine (HAWT).

The urgency for adopting alternative energy sources becomes evident as traditional power generation methods deplete finite resources and contribute to environmental degradation [4]. Fossil fuel-powered generators prevalent in the region strain economic resources and emit pollutants that contribute to global warming and air pollution [5]. Therefore, exploring renewable energy options, specifically wind power, is a compelling avenue for Lagos State University of Science and Technology.

Acknowledging the pivotal role played by the Mechanical Engineering Department in supplying alternative power to the institution, this study delves into the intricate technical and environmental dimensions of wind power generation. The introduction sets the stage by spotlighting the existing energy landscape, illuminating the environmental repercussions of current practices, and advocating wind power as an integral solution [6]. Beyond a mere theoretical proposition, the subsequent sections of this research promise a thorough analysis, combining advanced mathematical models with practical data collection methods. Through this, the study seeks to evaluate the viability and multifaceted benefits of integrating wind energy within the academic infrastructure of Lagos State University of Science and Technology. In doing so, it aspires to contribute tangibly to a sustainable, resilient, and forward-thinking energy future for the institution and its wider community.

Initially, utility-scale wind turbines emerged with two- and three-bladed designs, which were affordable for their time but considered small, inefficient, and primitive by 21st-century standards [7]. However, this paper aims to assess the horizontal axis wind turbine (HAWT) performance featuring a five-bladed configuration, as illustrated in Figure 1.

Figure 1: Five-Bladed Horizontal Axis Wind Turbine (HAWT)

1.1 Current Energy Landscape and Environmental Repercussions

The contemporary energy scenario at Lagos State University of Science and Technology, and, by extension, across Nigeria, is characterized by a heavy reliance on conventional power sources, predominantly fueled by fossil resources. The use of fossil fuel-powered generators remains pervasive, providing a substantial portion of the institution's energy needs [8]. However, this conventional approach comes with its set of economic and environmental challenges.

Economically, the cost implications of continually relying on fossil fuel-driven generators greatly burden the institution's budget. Maintenance, fuel procurement, and the periodic replacement of generators contribute to a recurring expenditure that hampers financial resources that could be allocated to other essential academic and infrastructural needs.

Environmental repercussions form a critical dimension of this energy landscape. The combustion of fossil fuels in generators releases a cocktail of pollutants, including carbon dioxide (CO2), carbon monoxide (CO), sulfur dioxide (SO2), and nitrogen oxides (NOx) [9]. These pollutants contribute to local air quality degradation and have far-reaching consequences on global climate patterns, adding to the collective impact of anthropogenic activities on climate change [10].

Moreover, the reliance on fossil fuels perpetuates the carbon-intensive energy model, exacerbating Nigeria's carbon footprint [11]. As a responsible academic institution situated within a global context of heightened environmental awareness, Lagos State University of Science and Technology faces the imperative to transition towards cleaner and sustainable energy alternatives.

1.2 Wind Power as a Viable Solution

In response to the challenges the current energy landscape poses, the introduction posits wind power as a viable and transformative solution. Wind energy stands out as a renewable resource with the potential to alleviate both economic and environmental concerns [12]. Unlike finite fossil fuels, wind is an abundant and perpetual resource, making wind power an attractive option for long-term sustainability [13].

The technology of wind turbines, exemplified by the five-bladed horizontal axis wind turbine (HAWT) under consideration, represents a mature and proven method of harnessing wind energy for electricity generation. This introduction not only advocates for the adoption of wind power but sets the stage for a comprehensive exploration of its technical feasibility, economic viability, and the positive impact it can have on reducing the institution's carbon footprint. In doing so, the study aspires to contribute valuable insights that extend beyond theoretical propositions, offering a roadmap for practical implementation and sustainable energy integration at Lagos State University of Science and Technology.

2 Literature Review: Transitioning from Fossil Fuels to Renewable Energy with a Focus on Wind Turbines

The literature has extensively documented the environmental and societal impacts of fossil fuels. Greenhouse gas emissions from burning fossil fuels contribute significantly to climate change, causing global warming and adverse weather patterns [14]. Air pollution from combustion processes leads to respiratory illnesses and other health issues, impacting communities near industrial facilities [15]. Moreover, fossil fuel extraction and transportation pose risks of oil spills, habitat destruction, and water contamination [16]. The dependency on finite fossil fuel resources also raises concerns about energy security and geopolitical instability [17]

The search for sustainable alternatives has spurred interest in various renewable energy sources. Solar, hydroelectric, geothermal, and biomass energy have gained prominence due to their lower environmental impact than fossil fuels. Solar power, in particular, has witnessed significant advancements in photovoltaic technology, making it a viable option for decentralised energy production [18]. Hydropower and geothermal energy offer reliable and continuous power generation with minimal greenhouse gas emissions [19]. Biomass energy, derived from organic materials, provides an opportunity to repurpose waste for energy production [20].

Transitioning from fossil fuels to renewable energy sources involves technological, economic, and policy considerations. Technological innovation is crucial in developing efficient and cost-effective renewable energy systems. Government policies and incentives are pivotal in promoting renewable energy adoption [21]. The economic feasibility of renewables is improving, driven by the decreasing costs of solar panels and wind turbines [22]. However, challenges remain, such as intermittency issues in some renewable sources and the need for energy storage solutions [23].

Wind energy, harnessed through wind turbines, has emerged as a leading contender in the shift away from fossil fuels. The literature highlights the benefits of wind power, including its abundant and renewable nature, relatively low environmental impact, and the potential for decentralised energy production [24]. The two primary designs are horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT). HAWTs are more prevalent due to their higher efficiency, power density, and cost-effectiveness [25]. However, VAWTs, despite lower efficiency, offer advantages in simplicity of design and cost reduction, especially in smaller-scale applications [26].

Two main designs of wind turbines exist based on the arrangement of rotor blade axes: horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). The HAWT, aligned with the wind stream, is the most commonly used for both residential and commercial purposes. It boasts efficiency, high power density, low sensitivity to wind speed variations, and cost-effectiveness per unit of power output [27]. The VAWT design, which dates back to the oldest wind turbines, constitutes around 10% of modern wind turbines. The blades rotate around their upward axes, opposite to the wind direction and ground. While VAWTs offer advantages in terms of tower design simplicity and cost reduction, they exhibit lower power efficiency, typically ranging from 0.3 to 0.4, compared to the more recent and efficient HAWTs with a coefficient of 0.5 [28].

VAWTs are closer to the ground and often do not mount on towers, resulting in lower exposure to higher and more consistent winds experienced by HAWTs. However, the distinctive blade forces acting on Darrieus wind turbines can impose additional stress, potentially causing the blades to twist, bend, or break. Comparative studies between HAWTs and VAWTs offer valuable insights into their strengths and limitations. However, [33] conducted a performance comparison of HAWTs and VAWTs in urban environments, concluding that HAWTs are more suitable for areas with consistent wind patterns, while VAWTs perform better in turbulent wind conditions often found in cities. Another study by [34] compared the noise emissions of both turbine types, finding that VAWTs generally produce less noise, making them more suitable for residential areas. A study by [35] evaluated the feasibility of integrating wind turbines on the University of Leeds campus. The study used computational fluid dynamics (CFD) to model wind flow and identify optimal turbine locations. The results indicated that strategically placed small-scale wind turbines could provide up to 20% of the campus's electricity needs.

A technical assessment by [36] explored the potential for wind energy integration at MIT. The study considered wind resource assessment, turbine technology, and grid integration. The findings highlighted the economic viability of deploying medium-sized HAWTs, with a projected payback period of 7-10 years.

An economic analysis by [37] examined the implementation of VAWTs in New York City. The study analysed installation costs, energy output, and maintenance expenses. The results suggested that while initial costs are higher, the long-term economic benefits and environmental impact reductions justify the investment.

The integration of wind turbines in academic institutions has been explored in several studies. A case study by [38] evaluated the feasibility of wind power on university campuses, emphasising the potential for significant energy savings and educational benefits.

Similarly, [39] assessed the implementation of wind turbines in a Turkish university, highlighting the positive impact on energy costs and sustainability initiatives.

This study aims to build on this body of literature by investigating the feasibility of wind power generation at the Mechanical Engineering Department of the Lagos State University of Science and Technology. By focusing on the Mechanical Engineering Department, we aim to address technical and environmental challenges, comprehensively evaluating wind energy's potential in an academic setting.

3 Methodology

The study was conducted in four distinct steps. The initial phase involved a comprehensive wind speed survey (measured in m/s) conducted around the Mechanical Engineering Department. The primary objective was to determine the minimum and maximum wind velocities at various locations for twelve months, with data logged every 2 hours to capture both daily and seasonal variations and used to identify the area with the highest wind speed potential.

Following this, the second step focused on the procurement of a 3000-watt, five-bladed horizontal axis wind turbine (HAWT). This turbine was selected based on its capacity to generate electricity at a wind speed of 2m/s, as determined from the minimum wind speed recorded at a height of 10m.

The third step involved the utilisation of the collected wind speed data to calculate both the minimum and maximum wind power at different elevations. Additionally, the fourth step encompassed the re-engineering of the sourced FZ-3000 HAWT. This process aimed to mitigate galvanic corrosion, followed by rigorous testing and, ultimately, installing and commissioning the five-bladed wind turbine.

The data obtained from the study underwent thorough analysis and visualisation, revealing a correlation between wind speed and elevation. Specifically, it was observed that wind speed increased with elevation and vice versa. The turbine's minimum starting speed was identified at 10m, and it was established that the maximum wind speed did not surpass the rated wind speed or the turbine's survival wind speed. The calculated shear exponent of the environment 0.2448 aligned with the shear exponent range characteristic of environments with relatively tall trees and buildings. Additionally, the electrical voltage (measured in volts) is assessed with a voltmeter, and the electric current (measured in amperes) is determined using an ammeter attached to the cable and directly connected to the generator. As shown in Figure 2, a digital anemometer is employed to quantify the velocity of the wind, measured in meters per second (m/s).

Figure 2: Wind Anemometer with Weather Clock Station

Table (1) shows the specifications of the FZ-3000 five-bladed horizontal axis wind turbine considered for the analysis.

Table 1: Specification of the FZ-3000 model of the five-bladed horizontal axis wind turbine.

Model	FZ-3000
Generator Rated Power	3000W
Wheel Diameter	1.2m
Blade length	580mm
Number of blades	5
Blades material	Nylon
Rated wind speed	13m/s
Start-up wind turbine	2m/s
Survival wind turbine	40m/s
Output voltage	12V
Generator type	Three-phase permanent magnet AC synchronous

3.1 Mathematical Formulation of Wind Shear Exponent

Wind speed at hub height at a particular point is related to the gradient of the earth's surface called wind shear. Wind shear is an occurrence on the earth's surface over a small distance during which wind speed increases with vertical elevation above ground level and directly affects the wind power available at different hub heights. The effect of height on wind speed is especially due to the shear exponent and may be calculated using the power law equation [29].

$$V_2 = V_1 \cdot \left(\frac{Z_2}{Z_1}\right)^{\alpha} \tag{1}$$

$$\alpha = \frac{Log_{10}}{Log_{10}}\left[\frac{\frac{V_2}{V_1}}{\frac{Z_2}{Z_1}}\right] \tag{2}$$

Where;
V_1 = Wind speed at reference height Z_1
V_2 = Wind speed at height Z_2
Z_1 = Reference height (lower height)
Z_2 = Height above ground level (upper height)
α = wind shear exponent

3.2 Mathematical Formulation of Weibull Distribution

The Weibull distribution is used to approximate wind speed probability distribution occurring at a particular location during a period [30].

$$\int(v) = \frac{k}{A}\left(\frac{v}{A}\right)^{k-1} exp\left(-\left(\frac{v}{A}\right)^{k}\right) \tag{3}$$

3.3 Mathematical Formulation of the Maximum Power Available

How much power is moved to a wind turbine is straightforwardly relative to the thickness (density) of the air, the region cleared out by the rotor, and hence the block of the breeze speed.

The Albert Betz condition indicates the most extreme usable power P separated by a breeze turbine [31]. However, from Newton's First Law of Movement, the dynamic energy of an item having mass M and speed V moving with a consistent speed increase is equivalent to the work done W in dislodging the article from rest to a distance S under a power F, i.e.:
E = W = Fs
According to Newton's first law,
F = ma
Hence, E = mas (4)

Applying the third equation of motion:

$$V^2 = U^2 + 2as \tag{5}$$

$$Hence, a = \frac{(V^2-U^2}{2s} \tag{6}$$

But the initial velocity of an object, U =0

$$Therefore, a = \frac{V^2}{2s} \tag{7}$$

Substituting equation (7) in equation (4), we get,

$$E = {}^{1}\!/_{2}\, mV^2 \tag{8}$$

The power accessible in the wind is given by the change in energy per time:

$$P = \frac{dE}{dt} = {}^{1}\!/_{2}\, V^2 \frac{dm}{dt} \tag{9}$$

Nevertheless, the mass rate of flow is given by:

$$\frac{dm}{dt} = \rho A \frac{dx}{dt} \tag{10}$$

In addition, the change in distance per time is given by:

$$\frac{dx}{dt} = V \tag{11}$$

$$Thus, \frac{dm}{dt} = \rho \ x \ A \ x \ V \tag{12}$$

Putting equation (12) into (9), the power becomes:

$$\mathrm{P} = {}^{1}\!/_{2} \ x \ \rho \ x \ A \ x \ V^{3} \tag{13}$$

Where;
P = average power input in watts.
V= wind speed (m/s).
ρ = density of air at standard temperature and pressure in Kg/m^3.

But: Density, $$\rho = \frac{Mass\ (M)}{Volume\ (V)} \tag{14}$$

Mass = density x volume
And volume, (V) = Area (A) x Distance (D)
m = ρ x A x d
A = Swept Area in m^2

Therefore, the Power Coefficient of performance,

$$Cp = \frac{Power\ output\ (Pm)}{Power\ input\ (Pw)} \tag{15}$$

Hence,
Power output from the wind turbine, Pm = P_W x Cp
Inserting Betz Limit Cp in equation (13), the formula becomes:

$$\mathrm{Pm} = \tfrac{1}{2} \times \rho \times A \times v^3 \times Cp \tag{16}$$

But area A = π x r ^{2})

$$\mathrm{Pm} = \tfrac{1}{2} \times \rho \times \pi \times r^2 \times v^3 \times Cp \tag{17}$$

Where,
Pm = maximum power output in watts available from the generator.
Cp = coefficient of performance.
ρ = Mass density of air in Kg/m^3.
r = radius of the turbine blade in meters.
v = velocity of air in meters per second (m/s).
This shows that wind turbine power depends on the density of air, speed of air (velocity), and area swept out by the rotor.

3.4 Capacity Factor (CF)

Capacity factor is characterised as the proportion of the real power delivered by a turbine during a given period to the ideal greatest conceivable power (i.e. rated power) running fully without interruption [32]. A Wind turbine is economically viable if CF is at least 20%. Thus, the capacity factor is a pointer to the amount of energy a wind turbine generates in a particular.

$$Capacity\ Factor\ CF = \sum \frac{Actual\ power\ generated\ x\ Duration\ (hrs)}{Rated\ power\ x\ Duration\ (hrs)} \tag{18}$$

4 Data Analysis and Result

This research found the site with the highest potential wind speed at different vertical elevations. The average wind speed is obtained at a selected time of the day and different vertical elevations above sea level. It was used to calculate the shear exponent, available wind power, coefficient of performance, and capacity factor. Furthermore, the wind speed data is obtained from different locations in the Mechanical Engineering Department using a wireless wind anemometer from which daily mean wind speed was recorded on a two-hourly basis and at different vertical heights.

4.1 The Wind Shear Exponent

The wind shear exponent (α) was determined using Equation 2, considering the maximum wind speeds at the lower and highest elevations under consideration:

$$\alpha = \frac{Log_{10}}{Log_{10}}\left[\frac{\frac{V_2}{V_1}}{\frac{Z_2}{Z_1}}\right]$$

$$\alpha = \frac{Log_{10}}{Log_{10}}\left[\frac{\frac{7.82}{4.45}}{\frac{100}{10}}\right]$$

$$\alpha = \frac{Log\ 1.75730337}{Log\ 10}$$

$$\alpha = 0.245$$

The calculated wind shears exponent value of 0.245 aligns with the shear exponent typically associated with terrain featuring relative trees and occasional tall structures. This suggests that wind speed is influenced by terrain obstructions such as buildings and trees. Consequently, there is a recommendation to raise the hub height beyond 100 meters above sea level. This adjustment minimizes obstructions, allowing the wind turbine to operate unimpeded and capture sufficient wind speed and power. Also, the α value of 0.245 suggests a moderate increase in wind speed with height.

4.2 Weibull Probability Distribution

The given coordinates for the Mechanical Engineering department are (Latitude: 6.6145° N and Longitude: 3.5375° E). Using equation 3 with Shape Parameter (k): 2 and Scale Parameter (A): 6. The calculated probability density values for the given wind speeds are presented in Table 2.
Table 2 shows the wind speed values and their corresponding probability density values based on the Weibull distribution, and k =2 indicates a higher proportion of moderate to high wind speeds around that region. Figure 3 shows the Weibull Probability Density Function for wind speeds ranging from using a shape parameter k of 2 and a scale parameter A of 6. This curve demonstrates how the probability density varies with different wind speeds, illustrating the likelihood of different wind speeds occurring at the Mechanical Engineering department.

Table 2: Weibull probability density function for Wind Speeds

Wind Speed (m/s)	Probability Density
1.01	0.054549
1.212	0.064647
1.414	0.074318

1.616	0.083503
1.818	0.092148
2.02	0.100202
2.222	0.107617
2.424	0.114355
2.626	0.120374
2.828	0.125642
3.03	0.130132
3.232	0.133823
3.434	0.136698
3.636	0.138747
3.838	0.139962
4.04	0.140342
4.242	0.13989
4.444	0.138618
4.646	0.136539
4.848	0.133675
5.05	0.130049
5.252	0.125688
5.454	0.120624
5.657	0.114892
5.859	0.108529
6.061	0.101573
6.263	0.094065
Wind Speed (m/s)	**Probability Density**
6.465	0.086048
6.667	0.077564
6.869	0.068661
7.071	0.059387
7.273	0.049792
7.475	0.039926
7.677	0.029841
7.879	0.019585
8.081	0.009209

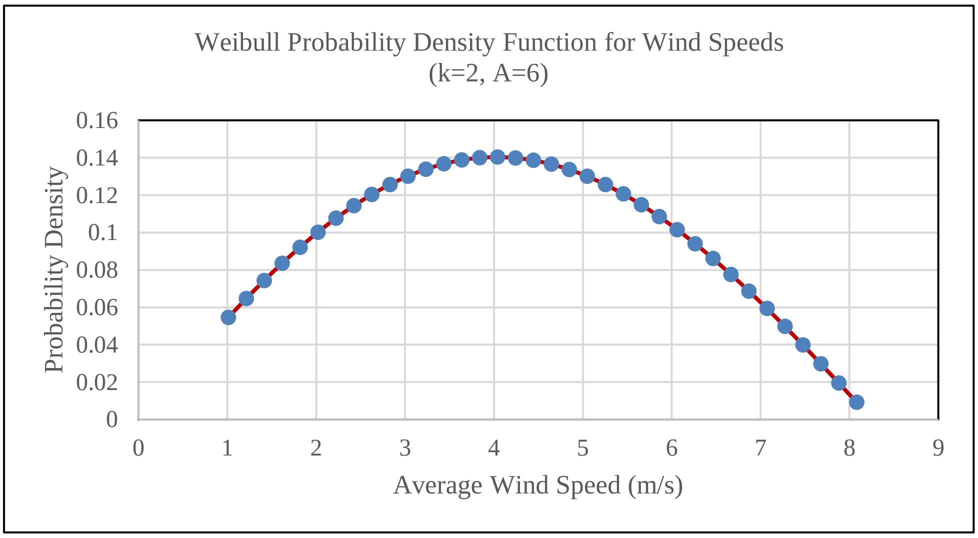

Figure 3: Weibull Probability Density Function for Wind Speeds

4.3 Capacity Factor

$$Capacity\ Factor\ CF = \sum \frac{Actual\ power\ generated\ x\ Duration\ (hrs)}{Rated\ power\ x\ Duration\ (hrs)}$$

$$Capacity\ Factor\ CF = \frac{1325.07 \text{ x } 10 \text{ x } 365}{3000 \text{ x } 10 \text{ x } 365}$$

$= 0.44169 \text{ x } 100$

$= 44.17\%$

The CF (Capacity Factor) value of 44.17% suggests that the Department of Mechanical Engineering is a viable option for large wind turbine installations. This indicates that the wind turbine operates at nearly half of its maximum capacity, reflecting a good potential for wind power generation in that area. However, there is room for improvement through regular maintenance, which can enhance both availability and reliability.

4.4 Average Wind Speed per Day

The results obtained on the characteristics of wind velocity at different elevations and times of the day are summarised in Table 3. Figure 4 indicates that the maximum wind velocity was highest in the morning and the evening, along with the minimum wind velocity. It also shows that power can be generated at any time of the day since the average minimum wind speed is above the cut-in speed (2m/s) for the wind turbine. This slight variation in wind velocity is caused by differences in solar heating received by the earth's surface as well as the rotation of the earth.

Table 3: Average wind speed at different times of the day

Time (hrs.)	Max. Average Wind Speed(m/s)	Min. Average Wind Speed (m/s)

6:30	6.47	2.91
8:30	4.96	3.28
10:30	5.31	2.46
12:30	5.04	2.06
14:30	6.48	2.27
16:30	5.81	2.14
18:30	5.39	3.17
20:30	6.54	3.73
22:30	5.38	3.51
0:30	5.85	3.83
2:30	6.17	3.12
4:30	6.41	2.95
6:30	5.73	3.41

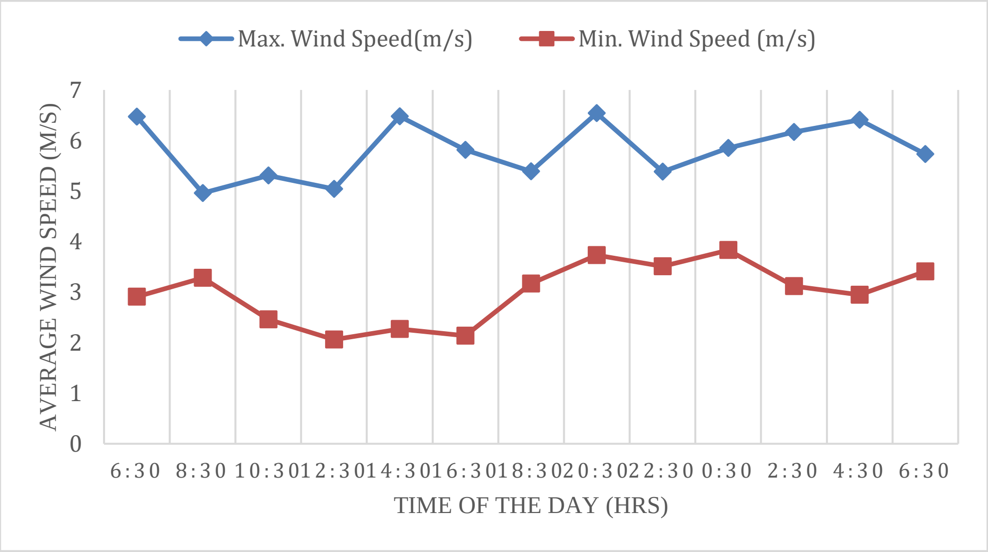

Figure 4: Average wind speed at a different time of the day

4.5 Wind Speed at Different Heights

Table 4 and the vertical profile of wind speed in Figures 5 and 6 summarise the maximum and minimum average wind speed characteristics at different altitudes. It also indicates that even at 100 meters above sea level, the maximum wind speed did not exceed both the rated turbine wind speed of 13m/s and the survival turbine speed specified at 40m/s. In addition, at 10 meters height, the minimum wind speed was not below the cut-in-speed of the wind turbine, which indicates from Table 3 that the wind turbine is capable of generating power at 10m height. Furthermore, the Table and figures indicate that more wind speed will be accessed and captured at heights above 10 meters. It also shows that wind speed increases with altitude; the higher the wind turbine tower, the more wind speed will be accessed and captured and, consequently, more power. Finally, from Table 3 and the vertical profile of wind speed, the turbine FZ-3000 will not be damaged at 100 meters elevation since the average maximum wind speed is still far below the cut-out speed.

Table 4: Average wind speed and power at different elevations

Vertical Height above ground (m)	Min. Average Wind Speed (m/s)	Max. Average Wind Speed (m/s)	Available Mini. Wind Power (W)	Available Max. Wind Power (W)
10	2.13	4.45	26.78	244.17
20	2.42	5.36	39.27	426.69
30	2.67	5.98	52.74	592.55
40	2.96	6.42	71.86	733.2
50	3.34	6.76	103.24	855.97
60	3.54	7.04	122.92	966.8
70	3.72	7.27	142.64	1064.69
80	3.89	7.48	163.11	1159.64
90	3.95	7.66	170.77	1245.39
100	3.98	7.82	174.69	1325.07

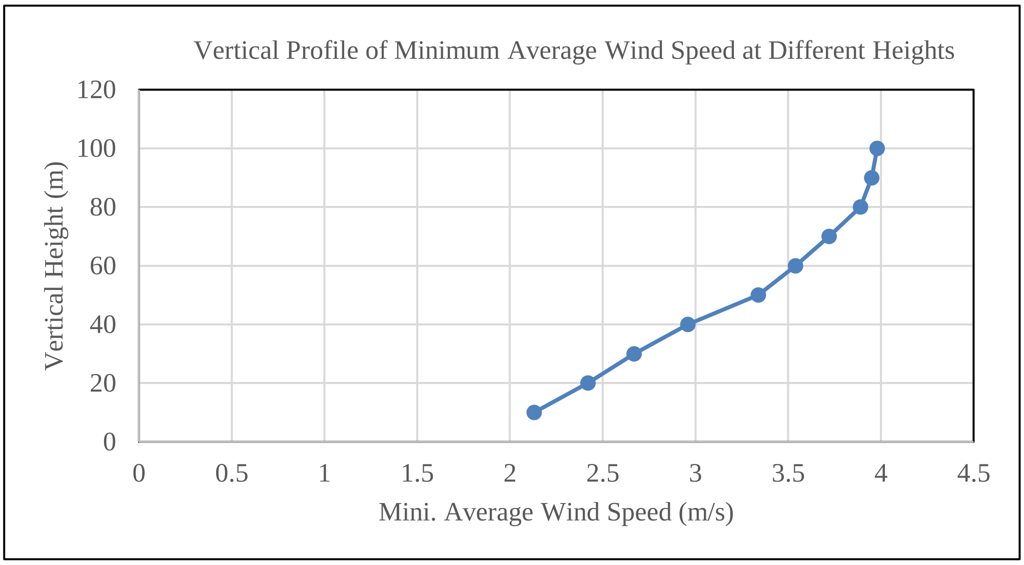

Figure 5: Vertical profile of minimum Average wind Speed at different height

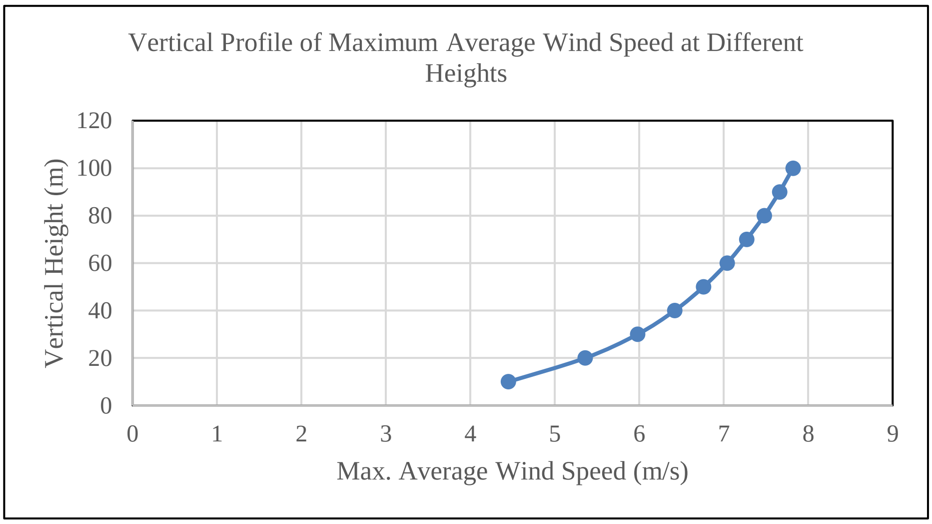

Figure 6: Vertical profile of maximum Average wind speed at different heights

4.6 Wind Power at Different Wind Speeds

Table 4, Figures 7 and 8 show that more power is generated at a speed higher than 2.13m/s. This is possible because wind speed increases with altitude. Since the HAWT FZ-3000 can generate 3000 watts of power, only about 1300 watts, and 170 watts were found to be the highest maximum and minimum power generated at 100 meters at 7.82m/s and 3.98m/s, respectively. The lowest minimum and maximum power generated at speeds of 2.13m/s and 4.45m/s are 26.78 watts and 244.17 watts, respectively.

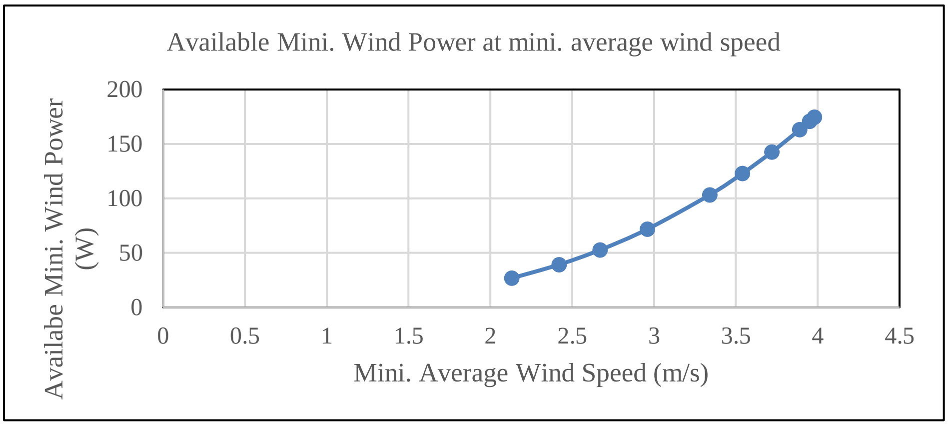

Figure 7: Available minimum power at minimum average wind speed

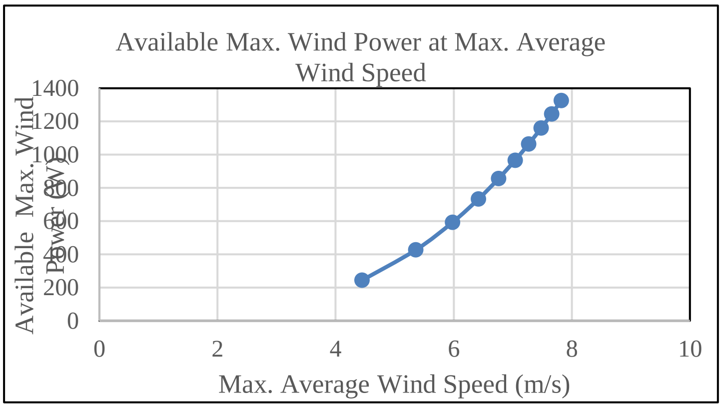

Figure 8: Available maximum power at maximum wind speed

4.7 Available Wind Power at Different Elevations

The data in Table 4 and the analysis in Figure 9 show the vertical profile of the minimum wind power at different heights, which indicates that the wind turbine can generate electricity at 10 meters in height and above. This agrees with the wind turbine's minimum starting speed (2m/s). Also, Figure 10 shows that the vertical profile of the maximum wind power is below the rated power of 3000 watts of the turbine. Since the HAWT FZ-3000 can generate 3000 watts of power, only about 1300 watts, and 170 watts were found to be the highest maximum and minimum power generated at 100 meters, respectively, there is room for more power generation. While the lowest minimum and maximum power generated at 10 meters are 26.78 watts and 244.17 watts, respectively. More so, the figures indicate that if the turbine tower is raised above 100 meters high and free from obstacles, more wind power will be generated, almost equal to the rated power of the FZ-3000 wind turbine.

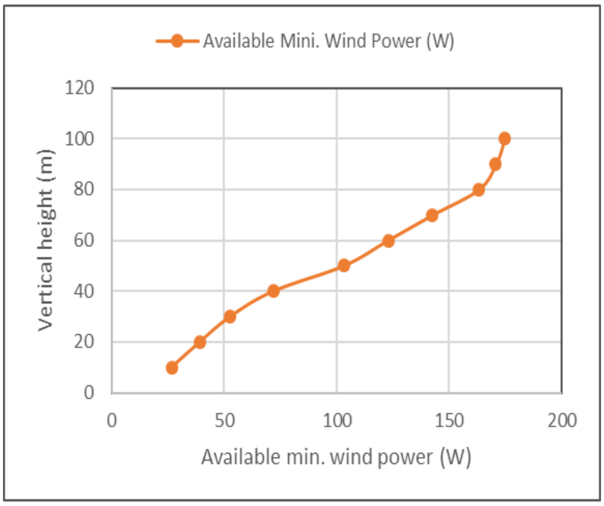

Figure 9: Available minimum wind power at different heights

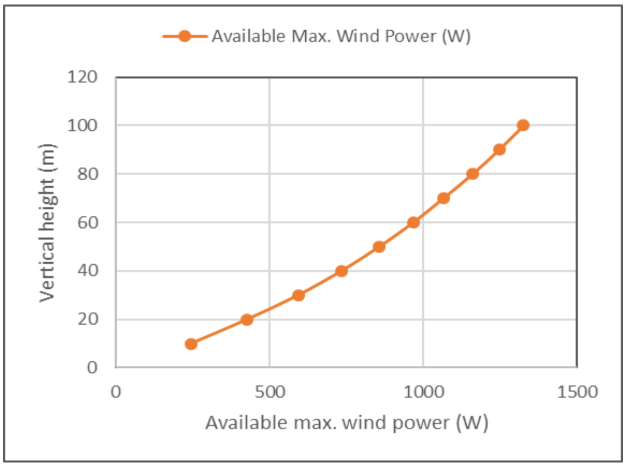

Figure 10: Available maximum wind power at different heights

4.8 Turbine Performance Analysis: Power Output Calculation

Using the wind speed data and the power curve of the FZ-3000 HAWT, the expected power output both maximum and minimum, at different heights was calculated using equation 17, as shown in Table 3, and plotted against vertical heights, as seen in Figures 9 and 10. The turbine's power output at different wind speeds was derived as follows:

i. Cut-in wind speed (2m/s): Minimal power output (107W)
ii. Rated wind speed (13m/s): Maximum power output (3000W)
iii. Cut-out wind speed (40m/s): Turbine shuts down to prevent damage

4.9 Economic and Environmental Impact

4.9.1 Economic Analysis:

i. Initial Investment: The cost of purchasing and installing the FZ-3000 HAWT was approximately $1,500.
ii. Operational Costs: Annual maintenance and operational costs were estimated at $200.
iii. Revenue projection: Using a capacity factor of 44.17%. Estimated annual electricity generation: 3000 W (Capacity) x 8760 hours (24 hours/day x 365 days/year) x 0.4417 = 11,607.876 kWh.
iv. Savings: The turbine is expected to generate approximately 11,607.876 kWh. annually, and the cost of electricity = $ 0.137 per kWh. The total annual savings is projected to be 11,607.876 x $0.137 per kWh = $1,590.279 per year in electricity costs.
v. Payback period (PBP): It is estimated to be 2 – 5 years

4.9.2 Environmental Impact

I. CO2 Emissions Reduction: The wind turbine will reduce CO2 emissions by approximately 10. metric tons per year (11,607.876 kWh/year x 0.92kg CO2/year / 1000), based on the average emissions factor for electricity generated by fossil fuels (0.92 kg CO2/kWh) [40].
II. Pollutant Reduction: Significant reductions in other pollutants like SO2 and NOx will improve air quality.

5 Conclusion

The findings of this study underscore the viability of wind power as a transformative solution for Lagos State University of Science and Technology. The data analysis reveals the site's substantial wind speed potential, especially at elevated heights, supporting the effectiveness of the selected five-bladed HAWT. The comprehensive mathematical formulations provide a deeper understanding of wind shear exponent, Weibull distribution, and maximum power available, contributing to the technical feasibility assessment. With a calculated Capacity Factor of 44.17%, the study suggests that wind power integration in the Mechanical Engineering Department is not only viable but holds promise for significant energy generation. Further recommendations include regular maintenance to optimise turbine performance, ensuring both availability and reliability in the pursuit of a sustainable and resilient energy future for the institution.

Building on the insights gained from this study, several avenues for future research are identified to further enhance the implementation and sustainability of wind power at the institution. Future research endeavours should delve into the exploration and evaluation of advanced wind turbine designs. Investigating emerging technologies, such as multi-rotor configurations or the application of innovative blade materials, could potentially unlock more efficient and cost-effective alternatives compared to traditional turbine models. A comparative analysis of these advanced designs against the current five-bladed HAWT would contribute valuable insights for optimising energy capture. Also, the optimisation of wind turbine placement is a critical aspect that warrants further attention. Conducting a comprehensive study considering topographical features, wind direction variability, and potential obstacles will help identify the optimal locations on the campus for maximizing energy yield. Implementing advanced algorithms for spatial analysis and computational modeling can enhance the precision of turbine placement strategies.

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