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Assessment of Wind Energy Potential for Small-scale Turbine Deployment at Akwa Ibom State University Community, Ikot Akpaden, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

As the need for clean energy is expanding, critical evaluation of renewable energy system has become increasingly important to the energy research community and stakeholders. This study examines the wind resource potential at Akpaden community and its suitable for siting wind turbine to support availability of electrical energy, research purpose and for technology innovation. Wind data is collected and tabulated at various time internal with respect to height for seven days. Statistical tool analysis was employed. Results show that there is a little variation in the morning and afternoon wind speed, an overall average of 4.09 m/s wind speed is obtained. The result is modeled into wind equation, at 12 m height, an average power of about 180 W can be obtained in a

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second. 300 W sizeable wind turbine was suggested for use. Result shows that useful energy can be obtained from wind available in Ikot Akpaden Community, though it is a little affected by height due to obstruction by building and tress, however, the limitations can be overcome when sitting in areas that is free from disturbances.

Keywords: Wind; height; velocity; turbine and power.

1. INTRODUCTION

Wind energy is one of the most important kinds of renewable energy resources in the world. The most effective, friendly to the environment and inexpensive power can be produce by wind, Wind energy is a renewable energy source. It does not contaminate and also it is inexhaustible and reduces the use of fossil fuels (Parajuli, 2016). Among many types of the renewable energy resources such as solar, wind, hydro, geothermal, biomass and ocean thermal power, Wind energy is one of the important resources to obtain electricity. It is widely used in many countries. During the last two decades, great attentions were paid towards the development of a best statistical model for describing wind speed frequency distribution. Weibull function is suitable to the observed wind speed data both at the surface and in the upper air (Lateef et al., 2019).

A Wind Turbine Generator is what makes electricity by converting mechanical energy into electrical energy. They do not create energy or produce more electrical energy than the amount of mechanical energy being used to spin the rotor blades. The greater the “load”, or electrical demand placed on the generator, the more mechanical force is required to turn the rotor. Wind power is used to produce electricity or mechanical power and supplies it to homes, laboratories, business, schools, etc. Wind turbine converts kinetic energy into mechanical energy and then the generator in the wind turbine converts this mechanical energy into electrical power (Srikanth, 2021).

Renewable energy has a direct relationship with sustainable development through its impact on human development and economic productivity. Renewable energy sources provide opportunities in energy security, social and economic development, energy access, climate change mitigation and reduction of environmental and health impacts (Asumadu-Sarkodie and Owusu 2016).

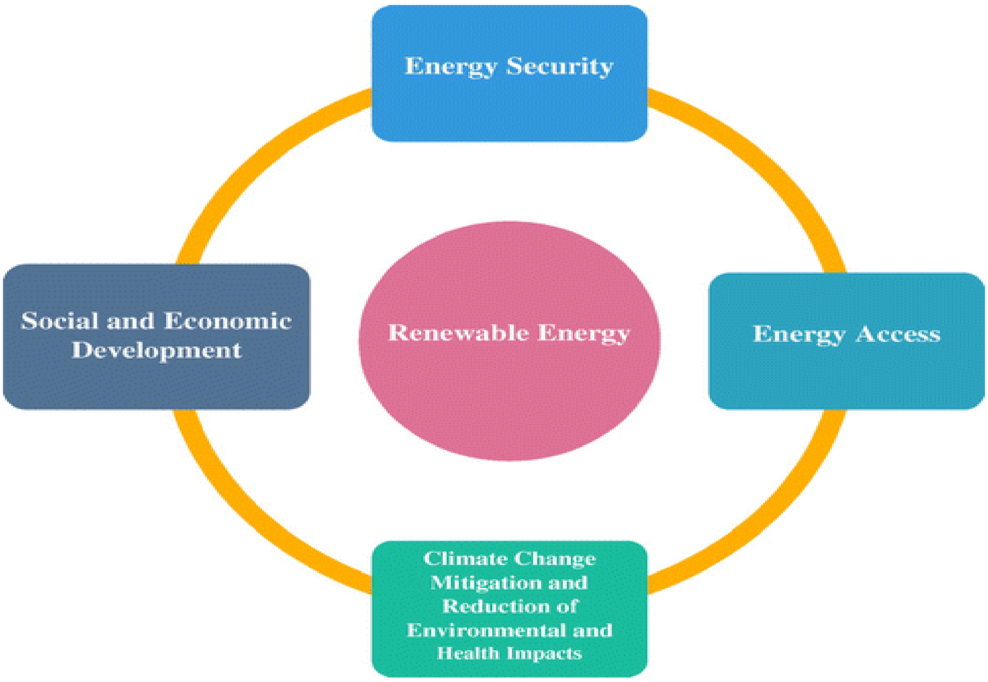


Fig. 1. Opportunities of renewable energy sources (Asumadu-Sarkodie and Owusu 2016)

2. REVIEW OF RELATED LITERATURE

By 2040, renewable energy is projected to equal coal and natural gas electricity generation. Several jurisdictions, including Denmark, Germany, the state of South Australia and some US states have achieved high integration of variable renewable resources. For example, in 2015 wind power met 42% of electricity demand in Denmark, 23.2% in Portugal and 15.5% in Uruguay. Inter-connectors enable countries to balance electricity systems by allowing the import and export of renewable energy. Innovative hybrid systems have emerged between countries and regions REN21. (2016).

The emergence of wind as an important source of the World energy has taken a commanding lead among renewable sources. Wind exists everywhere in the world, in some places with considerable energy density (Manwell et al., 2010). Wind energy harnesses kinetic energy from moving air. The primary application of the importance to climate change mitigation is to produce electricity from large turbines located onshore (land) or offshore (in sea or fresh water) (Asumadu-Sarkodie and Owusu 2016). Onshore wind energy technologies are already being manufactured and deployed on large scale (Manwell et al., 2010; Okpo and Nkan 2016).

In meteorology, wind speed, or wind flow speed, is a fundamental atmospheric quantity caused by air moving from high to low pressure, usually due to changes in temperature. Wind speed is commonly measured with an anemometer (Middleton and Spilhaus 1941). It is important to accurately describe wind energy of a particular area before developing into converting same to use. The need for extracting energy from wind is becoming of high demand as such, several analyses has been made by researchers in order to determine the behaviour of wind. Some gives wind data in a particular city (Middleton and Spilhaus 1941, Medugu and Malgwi 2005; Ngala and Ngala 2007; Oriaku et al., 2007; Fadare 2008 Nkan and Okpo 2016). Other reported wind speed data across the country (Fagbenle and Karayiannis 1994; Ojosu and Salawu 1990; Fadare, 2010; Okeniyi et al., 2015; Garba and Al-Amin 2014; Nkan et al., 2023; Ahmed et al., 2014; Udoakah and Ikafia 2017). The average wind speeds in Nigeria range from about 2 m/s to about 4 m/s with highest average speeds of about 3.5 m/s and 7.5 m/s in the south and north areas, respectively (Fagbenle and Karayiannis 1994; Awahet al., 2022). According to available data, Africa possesses a significant wind resources, with most countries experiencing average wind speeds between 3.5 and 10 meters per second at 10-20 meters altitude. Africa is already on the move when it comes to renewable energy development Muchiri, W. (n.d.). In Kenya, 17% of total power generation comes from wind energy, while Senegal enjoys 15% of its energy from wind. The Global Wind Energy Council of Africa Wind Power initiative launch the inaugural Status of Wind in Africa report, which provides a stock take of the wind industry in Africa and delivers a forecast of the continent's wind energy pipeline. The report identifies 83 installed wind farms across Africa, providing 9 GW of clean power. An analysis of the continent's project pipeline finds that capacity could increase by more than 900%, with 140 projects planned across Africa, representing another 86 GW of installed capacity on the horizon Muchiri, W. (n.d.).

There are several methods for analyzing wind resource data, some of these includes normal and lognormal, Rayleigh, Weibull and Gumbel probability distributions etc (Carta et al., 2009). Other analysis of wind speed using the daily wind data obtained from Nigeria Meteorological Agency Oshodi Lagos, employed Weibull, Lognormal and normal probability density function (Oyewole and Aro 2018; Abunike et al., 2021). Weibull distribution has been found to be accurate and adequate in analyzing and interpreting the situation of measured wind speed and in predicting the characteristics of prevailing wind profile over a place when large data is involved. Wind energy has proven to be one of the most viable sources of renewable energy. Investigations are underway with the main objective of improving the precision of power curve of wind resources. Due to the non-linear relationship between the power output of a turbine and its primary and derived parameters, Artificial Neural Network (ANN) has proven to be well suited for power curve modelling, Where Wind turbine power curves with six parameters have been modelled successfully (Pelletier et al., 2016).

Although wind power generation systems have evolved considerably in size, capacity and design, it has not been possible to build an ideal system, due to the behavior of the wind, as it varies in locations and in height, these affects the efficiency of a wind system (Edgardo-Portillo et al., 2019). Specifically, wind turbine is design best on technologies that can be implemented in such areas (Owman et al., 2000; Ekpo et al., 2021). Wind turbines mostly used are three-blade horizontal axis, since they take advantage of the variability of the winds, there are other technologies in developed countries for obtaining kinetic energy, by means of vertical Rotors that can be implemented Edgardo-Portillo (n.d.). Studies have proven mathematical equation for wind which serves to calculate the wind potential that is used by the wind turbine in addition to help us decide what type of technology to recommend for implementation (Núñez, 2015). Thus, in this study, the line graph and arithmetic mean are use in the analysis of tabulated wind data of a particular geographical area (Akpaden Community). Ability to determine wind energy in a particular location helps in selecting a type of wind turbine that will be most efficient for generating power.

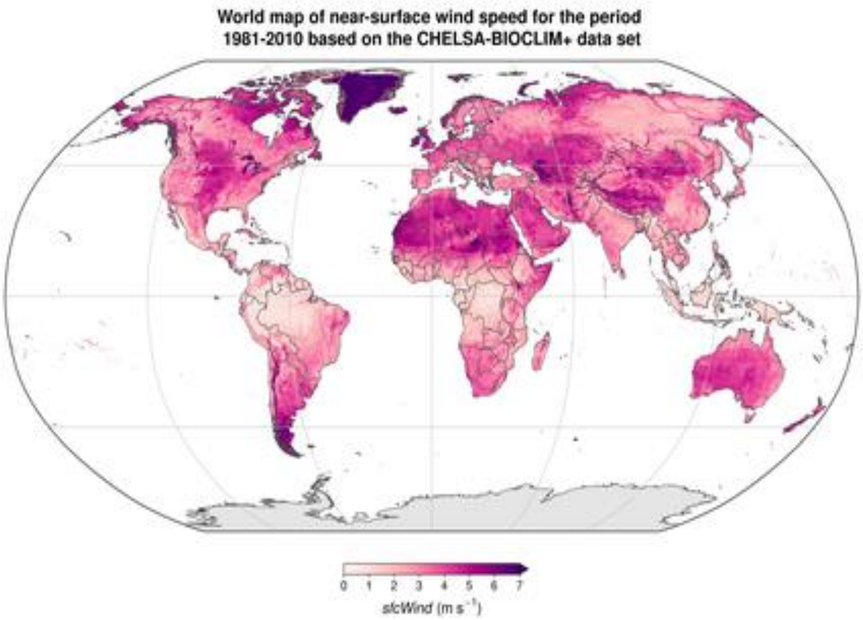


Fig. 2. Global distribution of wind speed at 10m above ground averaged over the years 1981–2010 (Middleton and Spilhaus 1941)

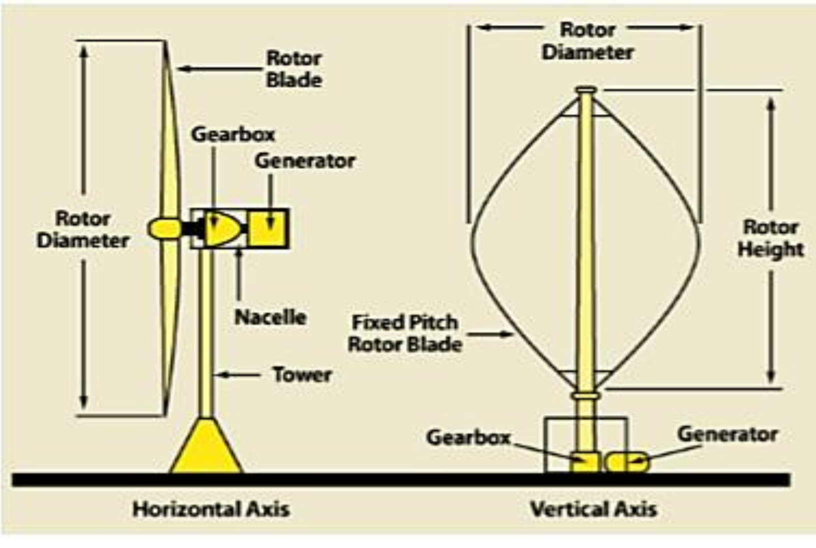


Fig. 3. Horizontal-axis wind turbine (HAWT) and vertical-axis wind turbine

Fig. 4. A cup and a hand-held anemometer

2.1 Types of Turbines

The two main types of wind turbines are the horizontal-axis wind turbine (HAWT) and vertical-axis wind turbine (VAWT) Edgardo-Portillo (n.d.).

2.2 Anemometer

There are many types of anemometers that is use in measuring wind speed, such as portable hand-held anemometers and those affixed to the ground at weather stations also known as cup anemometer. Anemometers are useful in areas like weather stations, ship navigation, aviation, weather buoys, and in wind turbine. Anemometer also has its applications in areas such as, for measuring the wind pressure, for measuring the flow of the wind and the direction of the wind. A cup anemometer consisted of four or three hemispherical cups on horizontal arms mounted on a vertical shaft. The air flow past the cups in any horizontal direction turned the shaft at a rate roughly proportional to the wind's speed. Therefore, counting the shaft's revolutions over a set time interval produced a value proportional to the average wind speed for a wide range of speeds (Middleton and Spilhaus 1941). A hand-held modern anemometer has a turning fan and a digital display screen where the measured wind speed is display in meters per second.

Theoretically, the anemometer's speed of rotation is proportional to the wind speed because the force produced on an object is proportional to the speed of the gas or fluid flowing through it. However, in practice, other factors influence the rotational speed, which includes turbulence produced by the apparatus, increasing drag in opposition to the torque produced by the cups/fan and support arms, and friction on the mount point (Middleton, 1969).

3. MATERIALS AND METHODS

In this study, wind potential is assessed in terms of its velocity at different height interval, critical values of the wind velocity are tabulated with the use of Anemometer at different time intervals for seven days. Each type of measure represents a succession of unique values and input assumptions that leverage duplication of data and which provides a common analysis flow. The results obtained is a characterization of a develop-able quantity and a useful wind resource that can be used to represent a good supply curve. Fig. 5 represent Akwa Ibom State University Ikot Akpaden Community, the area in which the experiment was carried out at a Longitude and Latitude (4.628^0 N, 7.500^0 E). (a) represent Nigeria as a country, (b) represents Akwa Ibom State, (c) is the study area, Ikot Akpaden Community.

3.1 Power Law of a Wind Turbine

A wind turbine usually converts the kinetic energy in the moving mass of the wind into rotational energy, the useful power (P) from the turbine is the ratio of the kinetic energy received over time Renewable Energy Institute. (n.d.).

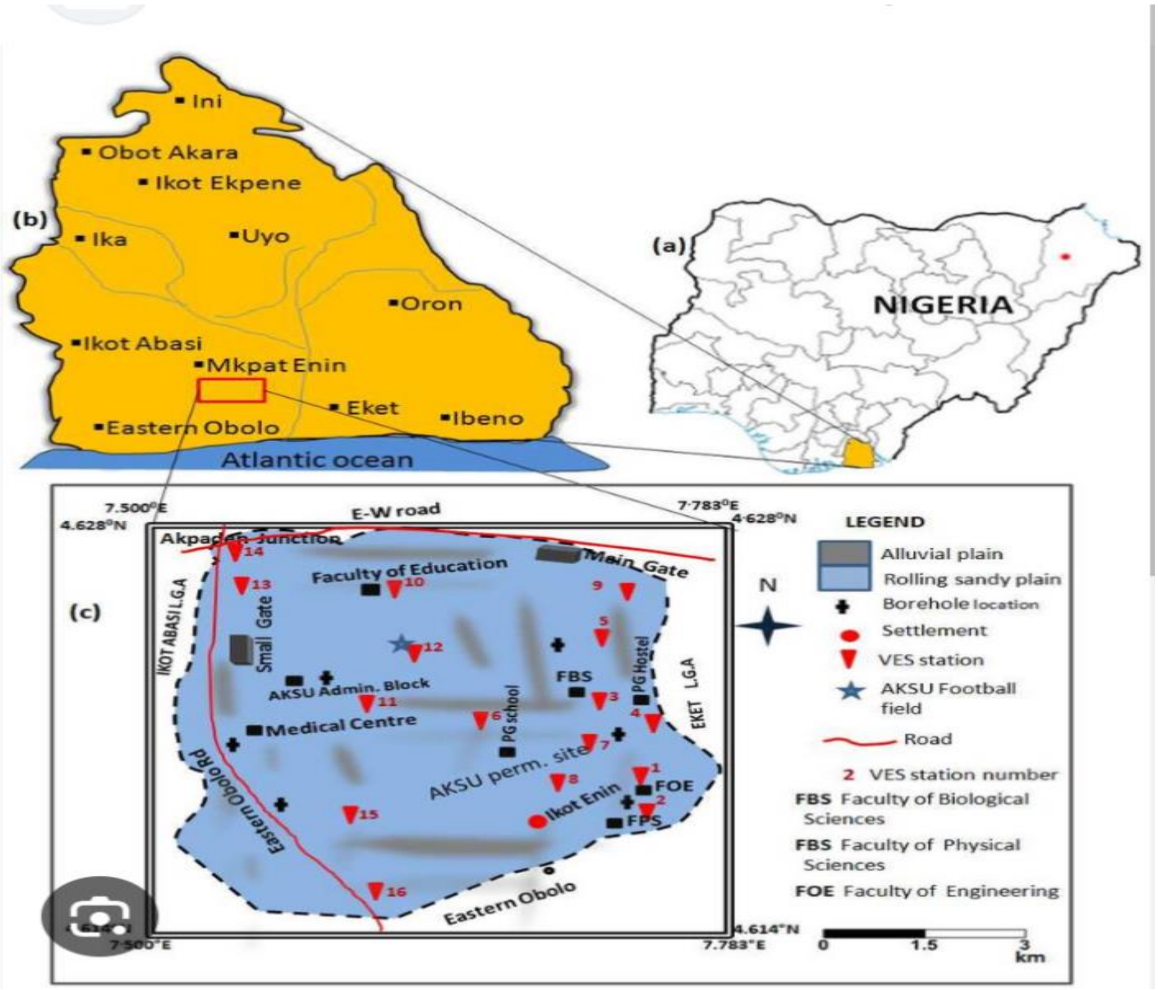
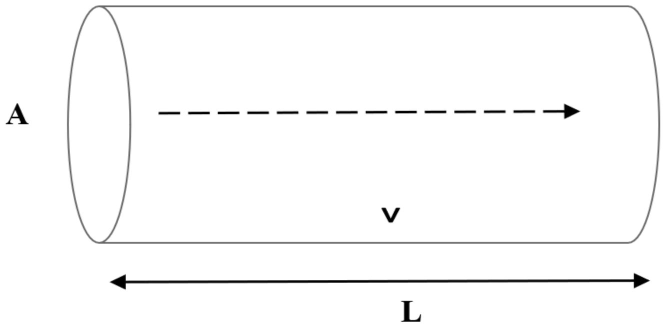


Fig. 5. Map showing the study area



Picture 1. Power Law of a Wind Turbine

Kinetic Energy (K.E) = $^1/_2\, mv^2$ (1)

Power (P) $= \frac{K.E}{t} = \frac{^1/_2 \times mv^2}{t} = {^1/_2} \times v^2 \times \frac{m}{t}$ (2)

As Mass flow rate $= \frac{\mathrm{m}}{\mathrm{t}}$ (3)

$\text{Distance (L)} = \text{Velocity} \times \text{Time} = \text{vt}$ (4)

$\text{Time (t)} = \frac{L}{v}$ (5)

$\text{Density } (\rho) = \frac{\text{mass}}{\text{volume}} = \frac{\mathrm{m}}{\mathrm{v}}$ (6)

$\text{Mass} = \text{density} \times \text{volume} = \rho \times \mathrm{v} = \rho \times \mathrm{A} \times \mathrm{L}$ (7)

$$\text{Power (P)} = \frac{1/_2 \times v^2 \times \rho \times A \times L}{\left(\frac{L}{v}\right)} = 1/_2 \times v^2 \times \rho \times A \times v \quad (8)$$

$$\text{Power (P)} = 1/_2 \times A \times \rho \times v^3 \quad (9)$$

Where, ρ = density of the air in kg/m^3 = 1.223 kg/m

A = πR^2 = Area of the circle swept by the rotor blades (m^2)

V = velocity of the wind in m/s

Thus, the power available to a wind turbine is based on the density of the air (usually about 1.223 kg/m^3), the swept area of the turbine blades (picture a big circle being made by the spinning blades), and the velocity of the wind. Of these, clearly, the most important variable input is wind speed. Wind speed is the most important variable because it is cubed, whereas the other inputs are also important but not as Wind speed.

4. RESULTS AND DISCUSSION

In this section, the result of wind speed at different height ranging from 2m to 12m was tabulated. Wind supply curve results and their variations across height is shown in the table and graph below. There is variation in the morning and afternoon wind speed as it is observed using line graph and arithmetic mean of the wind speed.

4.1 Analysis of Wind Velocity Against Height at Akpaden Community

Experimental analysis of wind velocity and power available with respect to height in Akwa Ibom State University Community main campus, Ikot Akpaden, Mkpat Enin Local Government Area, Akwa Ibom State is as shown in Table 1.

Table 1. Wind velocity in meters per seconds

Days	Time	Wind Velocity per Height in meters					
		2M	4M	6M	8M	10M	12M
Day 1	11:00-12:00	1.2m/s	1.3m/s	1.8m/s	2.2m/s	2.6m/s	3.0m/s
	3:00-4:00	2.6m/s	2.6m/s	3.0m/s	3.6m/s	3.8m/s	4.0m/s
Day 2	11:00-12:00	3.2m/s	3.6m/s	3.6m/s	4.0m/s	4.4m/s	4.4m/s
	3:00-4:00	3.6m/s	3.8m/s	3.8m/s	4.4m/s	5.0m/s	5.0m/s
Day 3	11:00-12:00	4.0m/s	4.0m/s	3.6m/s	4.0m/s	4.0m/s	4.4m/s
	3:00-4:00	4.2m/s	4.2m/s	4.2m/s	4.2m/s	5.0m/s	5.0m/s
Day 4	11:00-12:00	4.1m/s	5.0m/s	5.0m/s	5.0m/s	5.2m/s	5.0m/s
	3:00-4:00	3.0m/s	3.8m/s	3.8m/s	3.8m/s	3.9m/s	4.0m/s
Day 5	11:00-12:00	3.8m/s	3.8m/s	4.0m/s	4.0m/s	4.8m/s	4.8m/s
	3:00-4:00	4.8m/s	4.4m/s	4.8m/s	5.0m/s	5.2m/s	5.2m/s
Day 6	11:00-12:00	3.2m/s	4.8m/s	4.8m/s	5.2m/s	5.4m/s	5.4m/s
	3:00-4:00	3.8m/s	3.8m/s	4.2m/s	4.4m/s	5.0m/s	4.8m/s
Day 7	11:00-12:00	4.8m/s	4.8m/s	4.8m/s	4.6m/s	4.6m/s	4.8m/s
	3:00-4:00	3.2m/s	4.8m/s	3.8m/s	4.0m/s	4.0m/s	3.8m/s

Table 2. Day 1 morning and afternoon wind velocities against height

Velocity (A1) Morning	Velocity (A2) Afternoon	Height
1.2	2.6	2
1.3	2.6	4
1.8	3.0	6
2.2	3.6	8
2.6	3.8	10
3.0	4.0	12

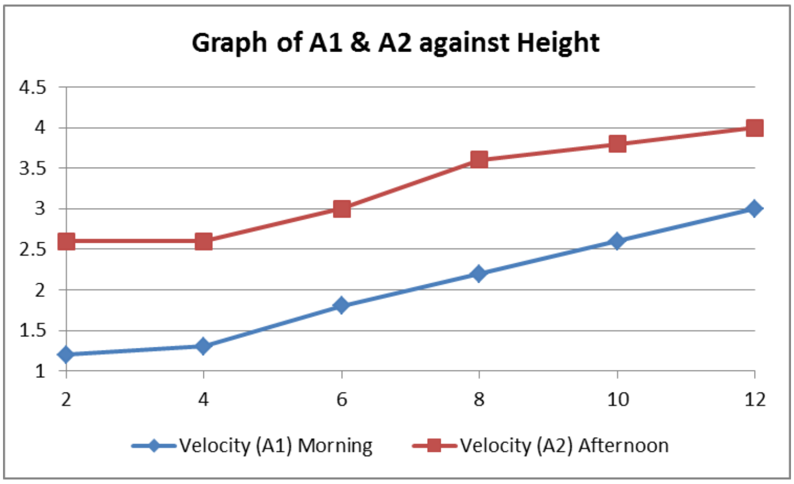


Fig. 6. Comparison of Day 1 wind velocities against height

Table 3. Day 2 morning and afternoon wind velocities against height

Velocity (B1) Morning	Velocity (B2) Afternoon	Height
3.2	3.6	2
3.6	3.8	4
3.6	3.8	6
4.0	4.4	8
4.4	5.0	10
4.4	5.0	12

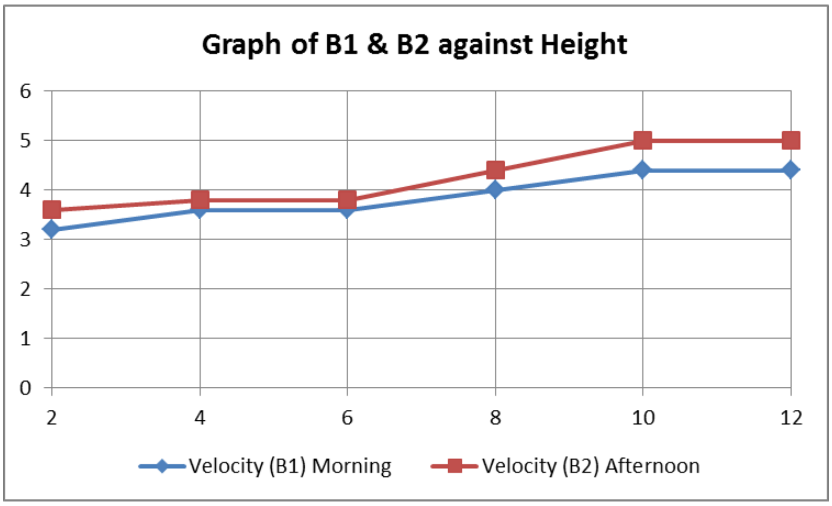


Fig. 7. Comparison of Day 2 velocities against height

Table 4. Day 3 morning and afternoon wind velocities against height

Velocity (C1) Morning	Velocity (C2) Afternoon	Height
4.0	4.2	2
4.0	4.2	4
3.6	4.2	6
4.0	4.2	8
4.0	5.0	10
4.4	5.0	12

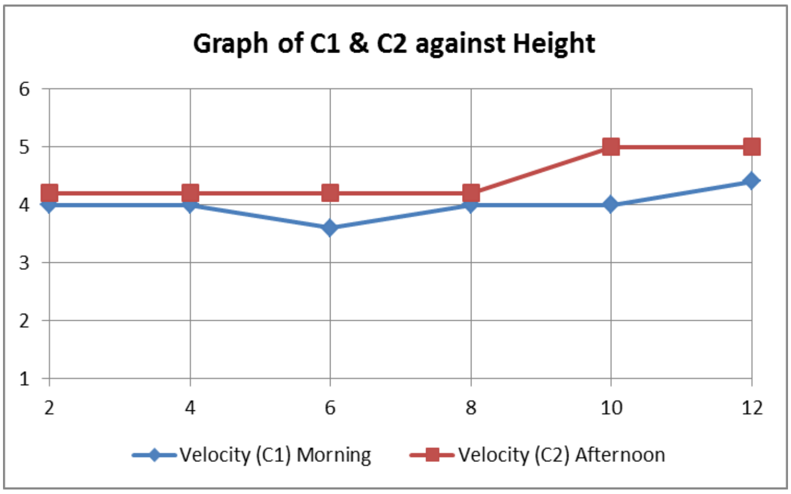


Fig. 8. Comparison of Day 3 velocities against height

Table 5. Day 4 morning and afternoon wind velocities against height

Velocity (D1) Morning	Velocity (D2) Afternoon	Height
4.1	3.0	2
5.0	3.8	4
5.0	3.8	6
5.0	3.8	8
5.2	3.9	10
5.0	4.0	12

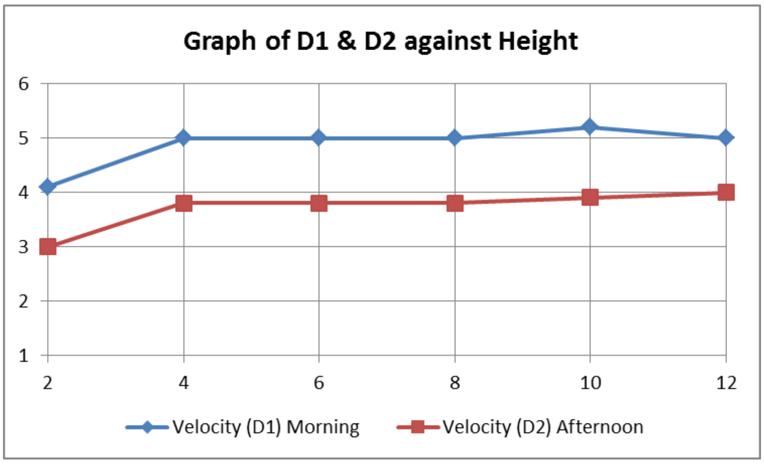


Fig. 9. Comparison of Day 4 velocities against height

Table 6. Day 5 morning and afternoon wind velocities against height

Velocity (E1) Morning	Velocity (E2) Afternoon	Height
3.8	4.8	2
3.8	4.4	4
4.0	4.8	6
4.0	5.0	8
4.8	5.2	10
4.8	5.2	12

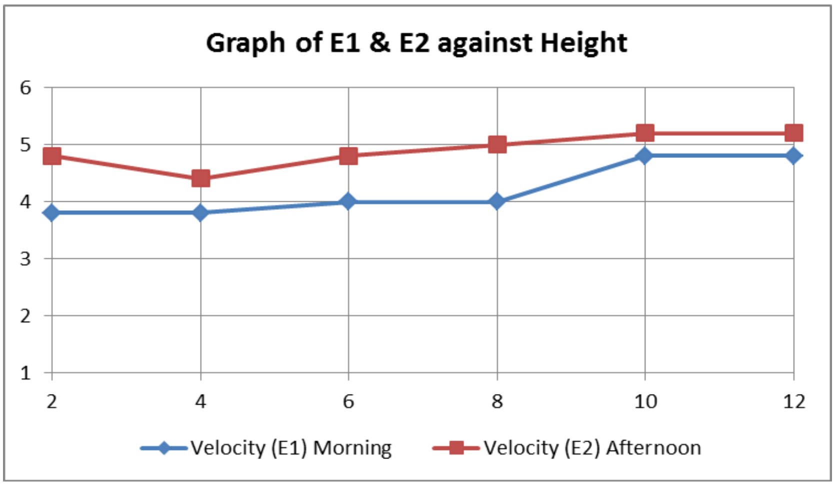


Fig. 10. Comparison of Day 5 velocities against height

Table 7. Day 6 morning and afternoon wind velocities against height

Velocity (F1) Morning	Velocity (F2) Afternoon	Height
3.2	3.8	2
4.8	3.8	4
4.8	4.3	6
5.2	4.4	8
5.4	5.0	10
5.4	4.8	12

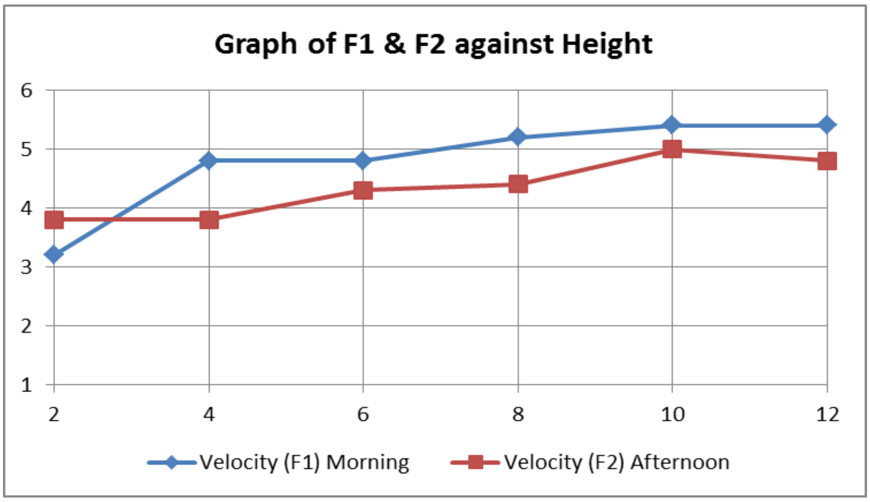


Fig. 11. Comparison of Day 6 velocities against height

Table 8. Day 7 morning and afternoon wind velocities against height

Velocity (G1) Morning	Velocity (G2) Afternoon	Height
4.8	3.2	2
4.8	4.8	4
4.8	3.8	6
4.6	4.0	8
4.6	4.0	10
4.8	3.8	12

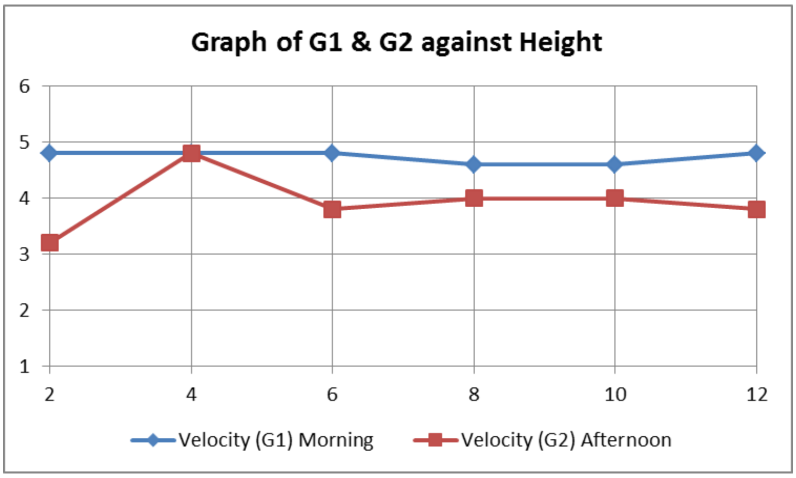


Fig. 12. Comparison of Day 7 velocity against height

Table 9. Average morning and afternoon wind velocities against height

Avg. Velocity Morning	Avg. Velocity Afternoon	Height
3.47	3.60	2
3.90	3.91	4
3.94	3.94	6
4.14	4.20	8
4.43	4.56	10
4.54	4.54	12

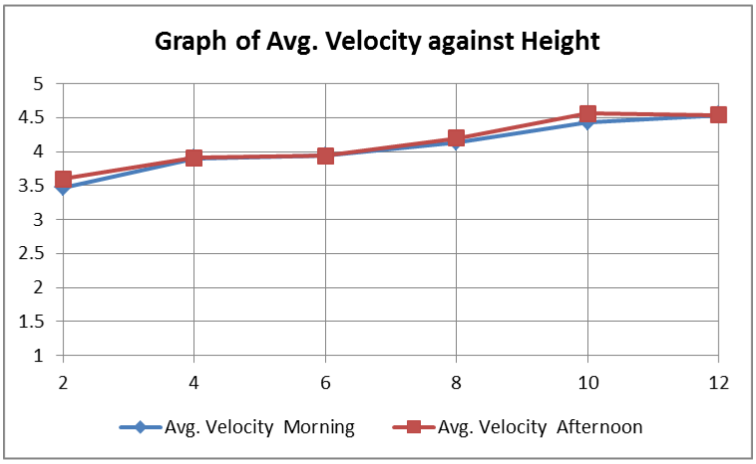


Fig. 13. Comparison of Average velocity against height

Table 10. Overall Average morning and afternoon wind velocity against height

Overall Avg. Velocity	Height
3.54	2
3.91	4
3.94	6
4.17	8
4.49	10
4.54	12

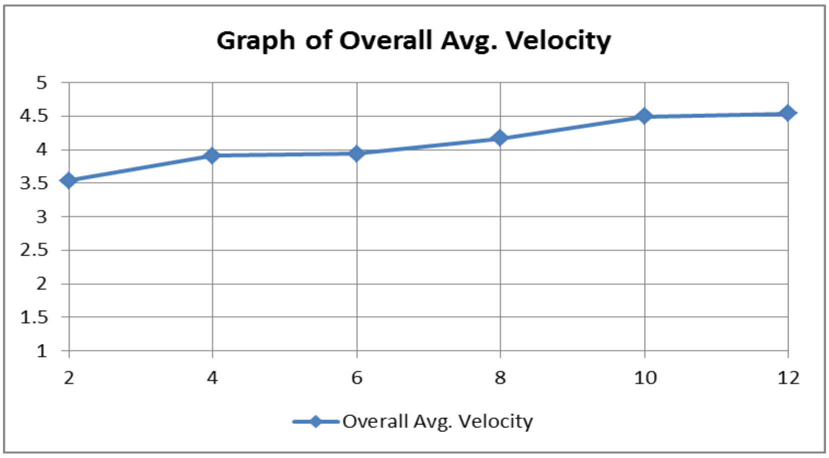


Fig. 14. Comparison of overall average velocity against height

Table 11. Average wind velocity in meters per second

S/N	Average Wind Velocity in (m/s)	Height in Meters (m)
1	3.54	2
2	3.91	4
3	3.94	6
4	4.17	8
5	4.49	10
6	4.54	12

Table 12. Average Wind Velocity and Power availability in hours

S/N	Average Wind Velocity in (m/s)	Height in Meters (m)	Power in a second	Power in an hour	Power in four hours
1	3.54	2	84.72	5083.2	20332.8
2	3.91	4	115.51	6930.6	27722.4
3	3.94	6	118.19	7091.4	28365.6
4	4.17	8	140.12	8407.2	33628.8
5	4.49	10	174.91	10494.6	41978.4
6	4.54	12	180.82	10849.2	43396.8

4.2 Modelling of Wind Turbine System using the Overall Average Velocity of the Wind with Respect to Height

Table 2 to 8 show that there is smaller improvement in value on the afternoon wind speed over the morning wind speed. Table 9 gives average of the morning and afternoon wind speed, while Table 10 shows that in an average, 4.09 m/s wind speed is available in the environment. Wind speed value increases with height in the environment, this is as a result of obstacle such as building and tress which resist the free flow of the wind.

Using the given data on equation 9 above, below are the values obtained, mathematically;

Power available in wind turbine is given by;

$$\text{Power (P)} = {}^{1}/_{2} \times A \times \rho \times v^{3} \qquad (10)$$

Using radius of the rotor to blade of the wind turbine as 1 meter,

Sweep area of the blade $A = \pi r^2 = 3.142 \times 1 \times 1 = 3.142\ m^2$ (11)

Where, ρ = density of the air in kg/m³ = 1.223 kg/m

V = velocity of the wind in m/s

therefore;

a) Power available in the wind at 2m height, 3.54 m/s velocity is;

(P)= $1/2 \times \rho \times A \times V^3$ = $1/2 \times 1.23 \times 3.142 \times 3.54^3$= 85.72 W

b) Power available in the wind at 4 m height, 3.91 m/s velocity is;
(P) = $1/2 \times \rho \times A \times V^3$ = $1/2 \times 1.23 \times 3.142 \times 3.91^3$= 115.51 W

c) Power available in the wind at 6 m height, 3.94 m/s velocity is;
(P) = $1/2 \times \rho \times A \times V^3$ = $1/2 \times 1.23 \times 3.142 \times 3.94^3$ = 118.19 W

d) Power available in the wind at 8m height, 4.17 m/s velocity is;
(P) = $1/2 \times \rho \times A \times V^3$ = $1/2 \times 1.23 \times 3.142 \times 4.17^3$ = 140.12 W

e) Power available in the wind at 10 m height, 4.49 m/s velocity is;
(P) = $1/2 \times \rho \times A \times V^3$=$1/2 \times 1.23 \times 3.142 \times 4.49^3$ = 174.91 W

f) Power available in the wind at 12 m height, 4.54 m/s velocity is;
(P) = $1/2 \times \rho \times A \times V^3$ =$1/2 \times 1.23 \times 3.142 \times 4.54^3$ = 180.82 W

The possible power that can be obtain from wind in a second from a turbine with the given characteristic in Ikot Akpaden community is given in the calculated data from a) to f). Results show that 180.82 W of power can be obtain from a turbine at 12 m height in Akpaden community, hence, a 300-watt, 12 V, three blade mini wind turbine can be efficient for wind power generation. Table 12 gives the available power in wind within the proposed location in seconds and hours using the given height intervals.

5. CONCLUSION

In this paper, the result of the analysis of wind velocity at various height interval, is used in modelling a sizeable wind turbine for the proposed area Akwa Ibom State University, Ikot Akpaden. Wind resource potential assessments underpin need for energy system planning. As clean energy ambitions have expanded, critical evaluation of renewable energy supply has become an integral part of wind potential assessments. These assessments are complex because of the intersection of the numerous factors and multiple disciplines involved, including energy systems analysis, technology expertise, land use and ecology, social science, and policy. However, when considering the limitation before sitting, the possibility of having a better result is sure.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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