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Empirical Study Of Wind Energy Potential In Calabar, Cross River State, Nigeria

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Abstract: This paper focuses on wind energy potentials in Calabar – a coastal city. The wind speed data were collected from Margaret Ekpo International Airport, Calabar (NIMET). The Objective of this study is to examine whether the wind energy in Calabar can generate sufficient energy to supplement electricity generation for the Calabar region. The primary data obtained is monthly mean in the form of wind speed for a period of 5year (2008 - 2012). These was used to estimate the available wind energy potential in calabar. The results show that, the annual wind is 1.3 m/s indicating Calabar as a low wind speed region. The wind power density value of 3.11W/m2 indicates that Calabar wind can only be used for small stand-alone wind power systems, such as battery charging and for powering street light and water pumps (fig 1, 2, 3 & 4). The weibull probability distribution scale parameters (k) are higher in values and variability than the shape parameter (c) for the monthly distribution. Calabar wind cannot be used to generate electricity because the wind speed data at 10m height doesn't exceed 2.5m/s due to the standard cut in speed.

Key Words: Wind, Solar Energy, Density, windmills and Calabar.

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Introduction

Wind energy is a form of converted solar energy. It simply means air caused by the uneven heating of the earth's surface by the Sun, Sanusi; (2007). The Sun's radiation heats several parts of the earth at different rates; different surfaces such as land, water, desert and forest areas absorb or reflect sun at different rates and most notably during the day and night, Ushiyama (1999), Osang et al (2013), Ewona et. al. (2014), Ojar et. Al. (2014). During the day, the air above the land heats up faster than the air over water, Ewona et. al. (2014), Udoimuk et. et. (2014). The warm air over the land, which is less dense, expands and rises, than the heavier, cooler air over the water which are more dense moves in to take its place, creating a conventional current known as wind, Swisher (1998), Ewona et. al. (2013). At night the motion of air is reversed because the air cools more rapidly over land than over water. Then, the large atmospheric air that the earth created because the land near the earth's equator is heated more by the sun than the land near North and South poles. The air has more energy when it is in motion. It possesses the energy of their motion (kinetic energy). Some portions of that energy can be converted to other forms of energy, Ushiyama (1999), Ewona et. al. (2014), Swisher (1998), Obi et. al. (2013). The energy that the windmills produce can be used in many ways, traditionally for grinding grain or spices, pumping water, sawing wood, hammering seeds, sailing and flying a kite. Nowadays, wind energy is mainly used to generate electricity, Ushiyama (1999). Wind energy is one of the renewable energy sources, because the wind will blow as long as the sun lives. The good sites for wind plants are the tops of smooth rounded hills, open plain or shore lines and mountain gaps that produce wind tunneling due to their low friction coefficients, Swisher (1998), Obi et.al. (2013), Udoimuk et. al. (2014). The wind turbine works in the opposite of an electric fan. Instead of using electricity to generate wind, like a fan, wind turbines use wind to generate electricity. The wind turns the rotor, which spins a shaft and connects to a generator that produces electricity. The wind power plant operation is not as simple as just building a windmill in a windy place. It is important to consider how fast, how much of the wind blow and how much energy can be generated which form basis of this research, Swisher (1998). According to the Global wind energy council website, Wind power has grown steadily over the last decade, at an average rate of 30% annually. Worldwide, the use of wind turbines on agricultural land, on top of mountain ridges and in the oceans total over 120GW of energy generation. Due to the fast market development, wind turbine technology has experienced an important evolution over time. The cost of wind energy was reduced by 30% between 1991 and 1997 and the cost reduction is foreseen to continue. Paulsen (1995) reported that the vestas group has installed more than 4500 wind turbines (640MW) world-wide. According to Anderson and Jenson (2000), by the end of 1998 the global installed capacity of modern grid connected wind turbines was 10,000MW, and the growth rates of installations world-wide were 30% - 40% annually. Environmental and economic benefits of utilizing the wind energy potential of Atlantic Canada. They showed that using current wind turbine technology, electricity can be generated at rates that are competitive with existing thermal power stations. They also discussed the benefits of development of a wind industry (Construction and running of wind farms) towards both the employment situation and the Environment, (Hughes and Scott, 1992). Clark *et al.,* (1988) have evaluated the performance of independent wind electric pumping systems, i.e., a wind turbine with a permanent-magnet alternator used to power standard three-phase induction motors connected to water pumps. The wind turbine was rated at 10 kW and produced a linear output of frequency between 30 and 90 Hz when alternator speed changed from 85 to 275 rpm. The alternator provided a frequency of 60 Hz at 9.2 m/s wind speed. A low head, high volume pump was thoroughly tested at several capacitances and two pumping heads (5 m and 15

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m). A high head, low volume pump was tested at 3pumping heads (70, 88, 105 m) and one capacitance. A medium head, medium flow pump was tested at a single head and capacitance. It was found that the motors operated at near the same efficiency as when operated from utility power, but pump efficiency was reduced when frequency exceeded 70 Hz, Swisher (1998). When countries around the world were developing into industrialized and developed nations, renewable energy resources were not developed on a large scale. Today as the world watches developing nation turns into industrial power houses, many people are advising that these newly developed nations start with renewable energy resources in order to save money as well as prevent more greenhouse gasses from entering our world atmosphere. Therefore, a renewable source such as wind is becoming a valuable resource around the world, Akpinar (2004). The various wind generator projects in Nigeria were neglected in the last decade due to increasing popularity and low price of crude oil. In recent times the high price of Petroleum products leads to attempts at restoring these windmills. However, difficulties in obtaining spare parts for models which were no longer being manufactured hindered the restoration. Also, some other factors that led to the failure of past wind generators are the assessment of wind energy potentials, feasibility studies on wind energy utilization, inadequate wind data base used as the bases for designing and building different prototypes that need to be considered in reducing locally manufactured windmills. The total inherent energy of the wind is determined by the following equation, Swisher (1998), Akpinar (2004)

$$P_{TOTAL} = \frac{1}{2} \rho A \mu^3 \text{..............................} 1$$

Where:-

P_{TOTAL}: Total power (watts)
ρ: air density (1.225kg/m3)
A: Rotor Swept Area (m^2)
μ: wind speed (m/s)

Equation 2 is used for altitude varying wind speed and that relates the speed to the height assuming a low surface roughness. It provides an easy method for calculating the mean wind speed at a given height and power law equation is given as

$$\mathcal{U} = \mathcal{U}i \left[\frac{z}{zi}\right] \frac{1}{7} \text{ .... } 2$$

Where:-

$\mathcal{U}$= modified wind speed
$\mathcal{U}i$ = wind speed data
z = height of turbine above ground level
z_i= normalize height.

There is increase in wind speed with increase in the height above the ground, due to the frictional drag of the ground, vegetation and buildings. It is important to put into consideration all these variables in order to harness the wind energy. The use of wind power for the supply of electricity broadens the energy base and reduces environmental pollution. It is particularly practical if it can be made economically competitive with conventional energy source. Amusan and sanusi (2007).

Sources of Wind

The sun heats up air masses in the atmosphere. The spherical shape of the earth, the earth's rotation, seasonal and regional fluctuations of the solar irradiance cause spatial air pressure differentials, Ewona et. al. (2014), Ushiyama (1999), Obi et. al. (2013) and Osang et. al. (2013). These are the source of air movements. Irradiation over supply at the equator is the source for compensating air stream between the equator and the poles. Besides, the partial compensation streams, less extensive air currents, exist due to the influence of local areas of high and low pressure. The Coriolis force divert the compensation stream between high and low pressure areas. Due to the rotation of the earth, the air masses in the northern hemisphere are diverted to the right and in the southern hemisphere to the left. Finally, the air masses rotation around the low pressure areas, Anyawu,(1995).

Nature of Wind

"Wind" is flow of air. Air has certain mass (kg) and mass density (Kg/m). Flow of air (wind) results in flow of mass (mass flow: Kg/s). The flowing mass has kinetic energy (KE). Hence wind is a natural source of kinetic energy, Ushiyama (1999), Osang et. al. (2013). The energy in the wind can be converted into useful mechanical energy by means of wind turbine, windmill, sails of ships etc. As a natural phenomenon in the atmosphere, there are two different origins of wind namely: -

i. Planetary Wind: - These are caused by daily rotation of earth around the polar axis and unequal temperature, between Polar Regions and equatorial regions.

ii. Local Winds: - These are caused by unequal heating and cooling of air over ground surfaces and ocean/lake surface during the day and night.

Uses of Wind

In human civilization, wind has inspired mythology, influenced the event of history, expanded the range of transport and warfare, and provided a power source for mechanical work, electricity, and recreation. Wind has powered the voyages of sailing ships across earth's ocean. Hot air balloons use the wind to take short trips, and powered uses it to increase lift and reduce fuel consumption, Ewona et. al. (2014), Sanusi; (2007).

Wind Speed and Direction

Wind is often described by two characteristic: wind speed and wind direction.

i. Wind Speed: Wind speed is the velocity attained by a mass of air traveling horizontally through the atmosphere.

ii. Wind Direction: Wind direction is the direction from where the winds blow e g.

90: East wind 180 south wind 270: West wind. 360: north wind.

Installed wind capacity in the USA has increased rapidly from the late 1980's and into the early 1990's, but this growth then declined. Swisher (1998) have showed the resurgence of installation and given a critique of the institutional and technological factors affecting the change. In 1996, nearly 16,000 wind generators were spinning, providing for the electrical Installed wind capacity in the USA has increased rapidly from the late 1980's and into the early 1990's, but this growth then declined. Swisher (1998) have showed the resurgence of installation and given a critique of the institutional and technological factors affecting the change. In 1996, nearly 16,000 wind generators were spinning, providing for the electrical needs of roughly one million residents in California, where just sixteen years ago, in 1980, the state had been without wind generators, Akpinar (2004). To explain this remarkable growth, Righter (1996) have analyzed four central factors: political climate, tax incentives, the PURPA Act, and the attitude of the public utility commission. Ushiyama (1999) have estimated that MHI (Japan) had exported more than 800 unit middle-sized commercial wind turbine generators to the United States and UK. Betts (2000) have believed that on-going wind tunnel tests in United States are expected to benefit turbine developers everywhere. Needs of roughly one million residents in California, where just sixteen years ago, in 1980, the state had been without wind generators. To explain this remarkable growth, Righter (1996) have analyzed four central factors: political climate, tax incentives, the PURPA Act, and the attitude of the public utility commission. Ushiyama (1999) have estimated that MHI (Japan) had exported more than 800 unit middle-sized commercial wind turbine generators to the United States and UK. Betts (2000) have believed that on-going wind tunnel tests in United States are expected to benefit turbine developers everywhere. Hughes and Scott (1992) studied the environmental and economic benefits of utilizing the wind energy potential of Atlantic Canada. They showed that using current wind turbine technology, electricity can be generated at rates that are competitive with existing thermal power stations. They also discussed the benefits of development of a wind industry (Construction and running of wind farms) towards both the employment situation and the Environment. Meibom and Sorensen (1999) have indicated that the official Danish energy plan Energy 21' called for a very high penetration of wind energy in the electricity sector. Consequently, Denmark is looking to install larger turbines in its existing offshore facilities, maximizing the energy output. Sorensen *et al.,* (2000) have summarized the experiences from the project consisting of 20 wind turbines at each 2 MW in Copenhagen harbor. Additionally they have drawn the perspectives for the future development of offshore wind power in Europe. Villars and Jorge (1998) have analyzed the technical-economic feasibility aspects of wind energy in Rio de Grande do Sul state, Brazil. With annual mean wind speed of 6.6 m/sand power density of 310 W/m2, and commercially available 1.65 MW wind turbines, Li(2000) has showed that a farm of 1038 MW capacity was economically feasible in Hong Kong. Lew (2000) has stated that the Inner Mongolia Autonomous Region (China) has already successfully disseminated over 150,000 small-scale wind electric generators to power households. Mc Eloy *at al.,* (2009), Mongolia sandwiched between Russia and China has a high potential for wind powered energy. As an emerging and developing country with a large land size, Mongolia is an excellent choice for renewable energy practices. Due to the fast market development, wind turbine technology has experienced an important evolution over time. The cost of wind energy was reduced by 30% between 1991 and 1997 and the cost reduction is foreseen to continue. Paulsen (1995) reported that the vestas group has installed more than 4500 wind turbines (640MW) world-wide. According to Anderson and Jenson (2000), by the end of 1998 the global installed capacity of modern grid connected wind turbines was 10,000MW, and the growth rates of installations world-wide were 30% - 40% annually. When countries around the world were developing into industrialized and developed nations, renewable energy resources were not developed on a large scale. Today as the world watches developing nation turns into industrial power houses, many people are advising that these newly developed nations start with renewable energy resources in order to save money as well as prevent more greenhouse gasses from entering our world atmosphere. Therefore, a renewable source such as wind is becoming a valuable resource around the world. The Copenhagen Accord also suggested that the use of small scale wind generator between 100KW and 150KW would be best suited for small towns, especially in southern Mongolia. It would most likely also be cheaper for the small communities in the long run (Boer, 2009). According to Elliot *et al*.**,** 2001, the NREL is continuously collecting data to improve the wind atlas maps and encourage the use of large-scale wind energy system. Mueller and Jansen (1986) have discussed the efforts by the Consultancy Services. Clark *et al.,* (1988) have evaluated the performance of independent wind electric pumping systems, i.e., a wind turbine with a permanent-magnet alternator used to power standard three-phase induction motors connected to water pumps. The wind turbine was rated at 10 kW and produced a linear output of frequency between 30 and 90 Hz when alternator speed changed from 85 to 275 rpm. The alternator provided a frequency of 60 Hz at 9.2 m/s wind speed. A low head, high volume pump was thoroughly tested at several capacitances and two pumping heads (5 m and 15 m). A high head, low volume pump was tested at 3pumping heads (70, 88, 105 m) and one capacitance. A medium head, medium flow pump was tested at a single head and capacitance. It was found that the motors operated at near the same efficiency as when operated from utility power, but pump efficiency was reduced when frequency exceeded 70 Hz. Renewable energies were known from early antiquity and were utilized in various fields. For example, windmills were one of the oldest prime movers and used for more than1400 years in Persia and more than 700 years in Europe (Ushiyama, 2000). The transition to water pumping and high speed wind turbines for electric power generation had occurred at the end of 19th century. During the last decade of the 20th century, it has been shown that the wind energy industry has achieved much in the way of technological improvements and market development so that it has the potential to supply power to the developed and developing countries. For example, the specific energy harvested by the best machines increased to about 1700 kWh / m2 in 1994 against only 580 kWh / m2 in 1986 and prices came down slipping below 900 ECU/kW for turnkey installations (Palz 1996). The new larger turbines with higher capacities are expected to make the wind energy a bigger player in the power industry (Bodamer 1999)

MATERIALS AND METHOD

Study Area

Calabar Metropolis is the capital of Cross River State, which is one of Nigeria's coastal State, located in the south-south region of the county, bordered by the Republic of Cameroon in the East and Nigeria state of Benue (North), Ebonyi and Abia (West) and Akwa Ibom (south-west). It occupies a total land area of 10,156 square kilometers, lying between latitude $4^0 28^0$ and $6^0 55^0$ North of the equator and longitude $7^0 5^0$ and $9^0 28^0$ East of Greenwich meridian (Osang et al 2013)

Data Source

The data obtained is the monthly wind speed for the period of 5years (2008-2012). The wind speed data were collected from Margaret Ekpo International Airport, Calabar (NIMET). The wind data were obtained from an anemometer at different heights. These will be used to estimate the available wind energy potential in calabar.

Methods

In a bid to estimate the potentials of wind energy for use in electric generation, a proper analysis and interpretation of the wind data collected over a period of time is necessary. The wind regime must be predicted to understand how windy or peaked the wind speeds mould is. The peaked and windy nature of a site is aptly described by the shape and scale parameters respectively, using the Weibull distribution.

Weibull Distribution

The Weibull distribution has a cumulative distribution function of the form

$$F(V) = 1 - \exp[-\left(\frac{v}{c}\right)^{k}] \qquad 3$$

From this distribution, the probability density function can be obtained by differentiating F(v) with respect to V.

$$f(v) = \frac{dF(v)}{dv} = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}\exp\left(-\frac{v}{c}\right)^{k} \qquad 4$$

Where k is the shape parameter. This k value is essential in certifying with a high degree of certainty the probability of observing winds speed. When the wind regime is clustered to a certain mean value, k increases. On the other hand, the scale parameter c, with units of m/s is the value of the wind speed predicted using the Weibull distribution and the mathematical Gamma of the k values. An area with high c value is an indication of the windy nature of the location. According to Ojosu, (1989), the values for k and c can be obtained using any of the following.

a) Energy pattern factor method
b) Weibull probability paper method
c) Standard deviations analysis

For the purpose of this work, the standard deviation of 'k' and 'c' with the following expressions:

$$k = \left(\frac{\delta}{V_m} - 1.086\right) \qquad 5$$

Where $(1 \leq k \geq 10)$

$$c = \frac{Vm}{\Gamma\left(1+\frac{1}{K}\right)} \qquad 6$$

Vm = mean velocity

δ = Standard deviation of the wind velocities, r(1+1/k) is the Gamma function of the expression $\left(1+\frac{1}{K}\right)$. The trio is obtained from these expressions;

$$Vm = \frac{1}{n}\sum_{i-1} V_i \qquad 7$$

In general teams, the Gamma is an integral function in X for example, defined by

$\int(x) = \int_o t^{x-1} e^{-t}\, dt.$

From equations 3.4 and 3.6, after a rigorous mathematical analysis, the values of V_m and ℓ can be written ethically with the Weibull's parameters as

$$\delta = \left[\boldsymbol{r}\left(1+\frac{2}{k}\right) - \mathbf{r2}\left(1+\frac{2}{k}\right)\right]^{0.5} \qquad 8$$

Or

$$\delta = \left[\boldsymbol{\Gamma}\left(1+\frac{2}{k}\right) - \boldsymbol{\Gamma}\left(1+\frac{2}{k}\right)\right] \qquad 9$$

Wind Power Density and Energy

The energy obtained from the wind at an instant of time is kinetic energy of the form,

$E = ½\, mv^2$.

The mass can be approximated to ρVA, Where
ρ is the wind's density,
V is the wind's velocity and
A is the associated Cross sectional area.
$E = ½\, (\ell AV^3)$

The speed is basically an approximate mean speed V_m; and on most occasions, it is convenient to express this energy in terms of a unit area s turbines have different turbine blades. With these modifications, the instantaneous power the wind can generate is mathematically expressed as:

$$\frac{\boldsymbol{\rho}}{\boldsymbol{A}} = \frac{1}{2}\rho AV_m 3 \qquad = \rho_2 \ell V_m^{3}$$

Since the density is constant, and V_{mean} changes, the wind power can then be written as

$$\frac{\rho}{v} = \frac{1}{2}\rho V^3 = \omega/m^2 \qquad 10$$

If ${}^{C}pd$ is the design power coefficient of the wind rotor,

$$P(v) = ½\, C_{pd}\, \rho_{Vm}^{3}\ w/m^2 \qquad 11$$

If the wind regime is over a wide distribution, the ρ (v) will also include the energy pattern factor (EPF) for the period under consideration. The EPF is the ratio of the virtual means wind power density to the wind power density calculated using only the mean wind speed (Dahonouni, 2008)

$$Vm = \frac{1}{nV_m^{3}} \sum_{i=1} (V_i)^3 \qquad 12$$

The extractible mean daily, monthly and annual energy equations are defined by the following relations (Tchnida, 2000)

$$E_{daily} = 24 \times 10^{-3}\ \rho\,(v)\ KWh/m^2 \qquad 13$$

$$E_{daily} = 24 \times 10^{-3}\ d.\,\rho\,(v)\ KWh/m^2$$

$$E_{yearly} = \sum_{n=1} (E_{monthly})_n\ (KWh/m^2/year) \qquad 14$$

Wind Power Density Using Weibull Parameters

In addition to the computation of wind power from the measured field parameters, calculation of wind power can be developed using the Weibull distribution analysis with the relationship below.

$$p(v) = \int ½\, \rho\, V^3 f(v)dv \qquad 15$$

Substituting the value for f(v)

$$p(v) = \int \frac{1}{2}\rho V^{3}\frac{k}{c}\left(\frac{v}{c}\right) e - \left(\frac{v}{c}\right) \qquad 16$$

Integrating as it stands

$$p(v) = \int \frac{1}{2} \rho C^3 \lceil \frac{K+3}{k} \ w/m^2$$

The associated energy over a given period ⌈ (hours) is expressed as

$$p(v) = \frac{1}{2} \rho C^3 \lceil \left(\frac{K+3}{k} \ T \ w/m^2 \right) \qquad 17$$

Most Probable Wind Speed

After calculation of the scale and shape parameters from the Weibull distribution, two meaningful wind speeds can easily be calculated, keyhani, (2010) Agbor et. al. (2013), Ewona et al (2013). The most probable wind speed for a given wind probability distribution is given as

$$V_{mp} = C[1 - 1/k]^{1/k} \qquad 18$$

Wind Speed Carrying Maximum Energy

The wind speed carrying maximum energy, according to Januil, 1995 is obtained as

$$V_{max,E} = C[1 - 1/k]^{1/k} \qquad 19$$

At certain values of K, the Weibull distribution changes from an exponential distribution to an approximately normal distribution between k-values of 1 and 3.5. At k = 2, the Weibull distribution reduces to the Ray/eight distribution. Equations 3.2 and 3.1 become.

$$f(v) = \frac{1}{2}\frac{V}{v_m} \exp - \frac{w}{4}\left(\frac{v}{v_m}\right)^2 \qquad 20$$

$$F(v) = 1 \exp - \frac{w}{4}\left(\frac{v}{v_m}\right)^2 \qquad 21$$

Where:

$$V_m = C \lceil (1+1/k)$$

Extrapolation of Wind Speeds at Different Heights

In order to obtain a minimum of the wind speed required for powering a turbine, low – wind areas can meet these criteria by erecting wind turbines at different hub weights. Since wind speed increases with height, it is only essential to estimate the wind speeds at heights other than that obtained by an anemometer. The extrapolation of wind velocity at different hub heights comprises a power law (Lysen, 1983; Gotcek *et al.,* 2007).

$$\frac{V}{Vo} = \left(\frac{h}{h_o} \right)^n \qquad 22$$

Where V is the wind speed extrapolated at a height h, V_o and h_o are the previous velocity at a known height h_0 respectively n is the surface roughness, a constants value ranging between 0.05 – 0.5 (Akpinar and Akpinar, 2005). The value of n can be obtained from this relationship (Ucar and Balo, 2009)

$$n = \left\{ \frac{0.37 - 0.088 / nV_o}{1 - 0.088 / n\, h_o} \ 10 \left(\right) \right\}$$

If k and c are also estimated at a new height h relative to ho, then (Vth), a new extrapolated velocity can be obtained as

$$V(h) = C(h)\, r\, (1 + 1 / k/(h))$$

Where

$$C(h) = C_0 \quad (h/h_0)\, t$$

$$K(h) = \frac{Ko(1 - 0.088/n\ (ho/10)}{(1- \ 0.088/n\ (h/10)}$$

$$t = \frac{(0.37 - 0.088/n/10)}{(1- 0.088/n(h/10)}$$

k_o and c_o are the normal Weibull parameters at a known height, likely at 10m height above sea level. The essence of these extrapolations is to obtain at least the minimum result in wind speed to initiate low-power turbines in less windy areas.

Results and Discussions

Results

Table 1: *showing Monthly Calabar Wind speed data in m/s for 5yrs (2008-2012) at 10m and its characteristics.*

Month / Year	2008	2009	2010	2011	2012	V m	s.d	K	C
Jan	1.806	2.174	0.884	1.648	0.886	1.4	0.5	3.1	1.6
Feb	2.226	2.415	2.456	0.485	1.083	1.7	0.8	2.2	1.9
March	0.761	2.343	1.098	0.738	1.107	1.2	0.5	2.1	1.3
April	1.836	2.424	1.303	0.693	1.118	1.4	0.6	2.5	1.6
May	2.107	1.992	1.125	0.477	0.456	1.2	0.7	1.8	1.3
Jun	1.752	2.324	0.994	1.077	1.159	1.4	0.5	3	1.6
July	0.395	1.796	0.951	0.957	0.964	1	0.4	2.5	1.1
Aug	1.591	2.048	0.398	0.933	1.181	1.4	0.6	2.5	1.6
Sept	1.485	1.924	1.471	1.017	1.045	1.3	0.2	5.1	1.4
Oct	1.731	1.941	1.392	0.842	1.012	1.3	0.3	3.6	1.4
Nov	1.41	1.629	1.161	0.692	0.94	1.2	0.3	3.3	1.2
Dec	1.702	1.985	0.667	0.693	0.819	1.1	0.5	2.2	1.3

APD	AED	F(v)	f(v)
2.6	1.9	0.5	0.6
8.3	5.6	0.5	0.4
2.9	2.2	0.5	0.6
5.3	3.8	0.5	0.5
2.9	2.1	0.1	0.5
2.6	1.8	0.2	0.7
0.8	0.6	0.2	0.8
5	3.7	0.2	0.6
1.5	1.1	0.3	1.3
1.7	1.3	0.3	0.9
1.1	0.8	0.3	1
2.6	1.9	0.2	0.6

Vm: Average wind speed in m/s
S.D (σ): Standard deviation.
K: Dimensionless weibull shape parameters
C: weibull scale parameter.
APD: Average power density in watt/meters square (W/m^2).
AED: Average energy density over 24hrs in Kilowatt hr/meter square (kWh/m^2).
F(v): Cumulative density frequency .
f(v): Probability density function

Table 2: *Extrapolated wind speed data at the height of 30m*

Month	Vm	K(h)	C(h)	APD	AED	F(v)	f(v)
Jan	2.3	3.5	2.4	8.4	6.2	0.5	0.5
Feb	2.5	2.5	2.8	15	10.1	0.5	0.3
Mar	1.8	2.4	2	4.9	3.6	0.5	0.4
April	2.2	2.8	2.4	9.9	7.1	0.5	0.4
May	1.8	1.9	2	5.8	4.3	0.5	0.3
Jun	2.1	3.4	2.4	8.3	5.9	0.5	0.5
July	1.5	2.7	1.7	3.1	2.3	0.5	0.6
Aug	2.1	2.8	2.4	9.4	7	0.5	0.4
Sept	2	5.6	2.1	5.6	4.1	0.4	0.9
Oct	2	4	2.1	5.9	4.4	0.4	0.7
Nov	1.7	3.7	1.9	3.9	2.8	0.5	0.7
Dec	1.8	2.4	2	4.5	3.3	0.5	0.5

Table 3: *Extrapolated wind speed data at the height of 50m*

Month	Vm	K(h)	C(h)	APD	AED	F(v)	f(v)
Jan	2.7	3.6	4.2	42.9	31.9	0.1	0.2
Feb	3	2.6	4.7	128.4	86.2	0.2	0.1
Mar	2.2	2.5	3.6	59	43.9	0.2	0.2
Apr	2.6	2.9	4.2	92.9	66.8	0.2	0.2
May	2.2	2.1	3.6	56.6	42.1	0.3	0.2
Jun	2.6	3.5	4.1	42.4	30.5	0.1	0.2
Jul	2	2.9	3.2	39.9	29.7	0.2	0.2
Aug	2.5	2.9	4.1	88.8	66.1	0.2	0.1
Sept	2.3	5.9	3.8	30.9	22.2	0.05	0.1
Oct	2.4	4.2	3.8	31.4	23.3	0.1	0
Nov	2.1	3.9	3.4	23	16.5	0.1	0.2
Dec	2.1	2.5	3.5	54.6	40.6	0.2	0.2

Table 4: *Computed monthly wind speed at 10m, 30, and 50m heights*

Month	10m	30m	50m
Jan	1.4	2.3	2.7
Feb	1.7	2.5	3
March	1.2	1.8	2.2
April	1.4	2.2	2.6
May	1.2	1.8	2.2
Jun	1.4	2.1	2.6
July	1	1.5	2
Aug	1.4	2.1	2.5
Sept	1.3	2	2.3
Oct	1.3	2	2.4
Nov	1.2	1.7	2.1
Dec	1.1	1.8	2.1

Table 5: *Computed average power density at different heights.*

Month	10m	30m	50m
Jan	2.6	8.4	42.9
Feb	8.3	15	128.4
Mar	2.9	4.9	59
April	5.3	9.9	92.9
May	2.9	5.8	56.6
Jun	2.6	8.3	42.4
July	0.8	3.1	39.9
Aug	5	9.4	88.8
Sept	1.5	5.6	30.9
Oct	1.7	5.9	31.4
Nov	1.1	3.9	23
Dec	2.6	4.5	54.6

Table 6: *Computed Average Energy Density for different heights*

Month	10m	30M	50m
Jan	1.9	6.2	31.9
Feb	5.6	10.1	86.2
Mar	2.2	3.6	43.9
Apr	3.8	7.1	66.8
May	2.1	4.3	42.1
Jun	1.8	5.9	30.5
Jul	0.6	2.3	29.7
Aug	3.7	7	66.1
Sept	1.1	4.1	22.2
Oct	1.3	4.4	23.3
Nov	0.8	2.8	16.5
Dec	1.9	3.3	40.6

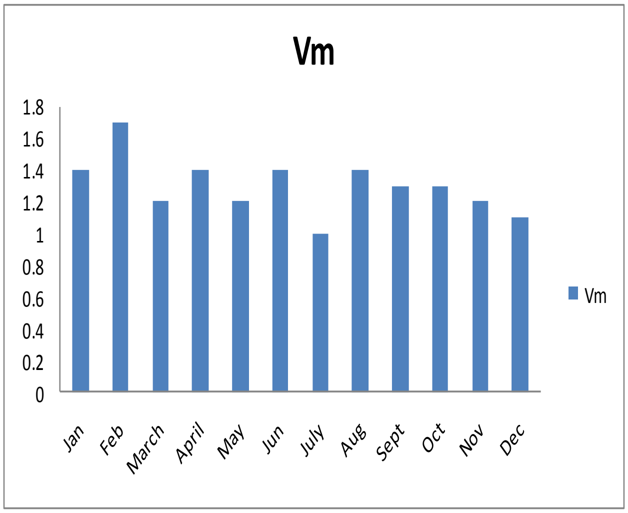

Figure 1: *Chart showing the wind speed at10m*

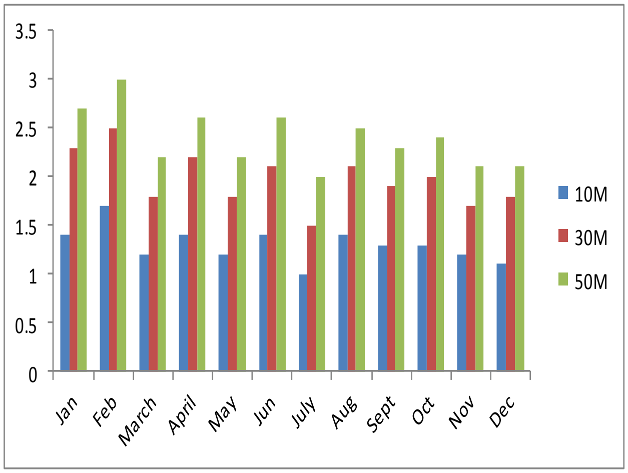

Figure 2: *Representation of mean monthly wind speed at 10 m, 30m, and 50m heights.*

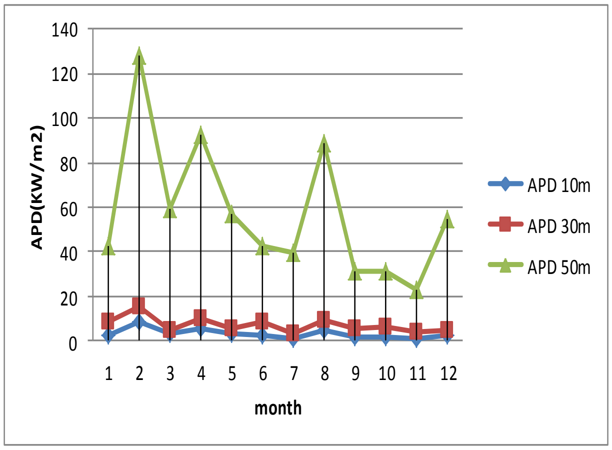

Figure 3: *Variation of APD against month at different heights.*

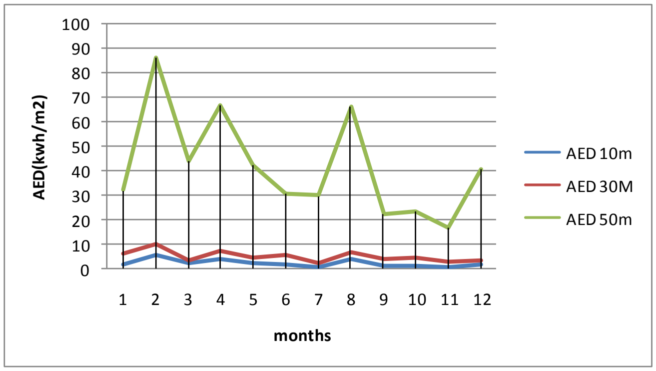

Figure 4: *Variation of AED against the month at different heights.*

Discussion of result

In this study, 5years of monthly mean wind speed data (2008-2012) measured at 10m height were obtained from NIMET, Calabar in table 1, the data were extracted and converted to working units, i.e. Wind speeds in knots and kilometers per hour were converted to meters per second as shown in table 1 with its characteristics. Using equation (22), the mean monthly wind speed at 30m and 50m were computed as shown in table 2, 3,4 while table 5 and 6 are the computed average power density and energy density at different heights. Figure 1 shows the monthly variation of the average wind speed for the whole year at 10m height. The wind speed has the maximum monthly mean value of 1.7m/s which arises in February, while the minimum value of 1m/s occurs in July. The overall mean wind speed for 5years is 1.3m/s. In figure 2, it shows the representation of mean monthly wind speed at three different heights. In figure 3, it shows the variation of average power density, which carries the maximum of 128.4W/m^2 and the minimum value is 0.8W/m^2. While in figure 4, the maximum average energy density is 86.2kWh/m^2 and the minimum is 0.8kWh/m^2.The annual mean power density for Calabar is 3.11W/m^2. The mean annual value for weibull shape parameter k is between 5.1 and 1.8, while the annual value of scale parameter c is between 1.9 and 1.1m/s. This result indicate that the maximum power production of the wind power system can be obtained in the month of February.

Conclusion

Based on analyses of the study, determination of the wind characteristics and wind power in Calabar is presented using weibull functions. The following conclusion can be drawn from the result: From the existing data, it is shown that the annual wind is 1.3m/s showing that Calabar is in a low wind speed region. The wind power density value of 3.11W/m^2 indicates that Calabar wind can only be used for small stand-alone wind power systems, such as battery charging and for powering street light and water pumps. The weibull probability distribution scale parameters (k) are higher in values and variability than the shape parameter (c) for the monthly distribution. Calabar wind cannot be used to generate electricity because the wind speed data at 10m height doesn't exceed 2.5m/s due to the standard cut in speed.

Recommendation

This work should be studied at different locations. Energy is essential to the economic and social development and will improve the quality of life in Calabar. More effort is needed to erect windmills for water pumping in rural areas with relative high wind potential. The result derived from this study encourages the utilization of wind energy on the coastal area.

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