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Evaluation of Wind Energy Potential for Power Generation in some Coastal Cities in Akwa Ibom State, Nigeria

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Abstract: The wind potential of three coastal sites, Ibeno (Latitude 4° 33' 54.2"N and Longitude 8° 4' 21.3"E), Oron (Latitude 4°48'26.53"N and Longitude 8°14'15.74"E) and Okobo (Latitude 4°41'48.48"N and Longitude 8°15'23.23"E) in Akwa Ibom State, Nigeria was investigated. Using data obtained from the Nigeria Meteorological Agency (NIMET) and the Maritime Academy of Nigeria, Oron for Ibeno, Okobo and Oron respectively for a period of five years (2012-2016), a statistical analysis was performed. Using empirical method, the overall average Weibull distribution parameters in terms of k and c, mean power density and mean wind speed were determined for the three locations to be 3.29, 4.74 and 4.11, 7.72, 6.54 and 6.40 m/s, 344.68, 236.10 and 185.18 w/m^2 and 8.24, 7.26 and 6.70 m/s respectively for Ibeno, Oron and Okobo. The results indicate that all the locations had a wind speed range higher than the 5-6 m/s recommended for electricity generation and a wind density value greater than 100 W/m^2. Resulting from the analysis, the overall annual energy production was projected to be 15.23, 10.45 and 8.19 GW for Ibeno, Oron and Okobo respectively, leading to the conclusion that the three cities located along the coastal lines of Akwa Ibom, would be viable for commercial wind power production.

Keywords: Energy production, Coastal Cities, Weibull distribution, Wind Power Potential, Wind Speed.

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1. INTRODUCTION

The role of energy in the economic, social and political development of any nation can never be over-emphasized. It is the catalyst required for a meaningful progress of any country. It has a major impact on every aspect of the socio-economic life, and it's not only a prime agent for generation of wealth but a significant factor in economic development and the driving force for industrialization of any society [1]. As vital as this resource is, in Nigeria, the gap between energy demand and its generation is constantly widening. Despite the abundance of energy resources in the country as observed by [2], the country has continued to experience shortage in supply of electrical power and has not been able to generate the maximum required amount of energy it needs for the growing population which is currently estimated to be over one hundred and eighty-five million (185,000,000) [3]. Even the electricity supply to the consumers that are connected to the grid is unreliable and often times described as epileptic [4]. The power generation report as released by the Ministry of power indicates that the peak generation to date is 5,074.7MW and the generation capacity is 6707.3MW [5]. Notwithstanding the various reforms carried out in the country's power sector, the energy situation in the country is yet to be structured and managed in such a way as to ensure sustainable energy development, most especially in the industrial sector. The International Energy Agency (IEA) yearly report continues to spotlights the deplorable energy situation in Nigeria alongside other developing countries. Specifically, the IEA report in 2016 while still reflecting on the energy access rate of developing countries, appraised the strides in the renewable energy sector to be remarkable and emphasis on the need for sustainability [6].

Several countries around the world are already working towards achieving the goal of environmental sustainability. One way of achieving this global goal is by gradually transitioning from the conventional fossil power generation technology to the non-conventional (renewable) method of power generation. Wind power, which is one of the renewable energy sources that has been used for millennia in a wide range of applications and has proven to be one of the most successful of all available sources of renewable energy offering relatively high capacities, with generation costs that are becoming competitive with conventional energy sources. The use of wind energy to generate electricity on a commercial scale, however, became viable only in the 1970s as a result of technical advances and government support. Currently, wind energy is one of the fastest developing renewable energy sources across the globe [7] and has the advantage of being suitable for use either in large scale, small scale, rural and remote areas. For Nigeria, seeking alternate sources of energy to meet her energy demand is essential. Therefore, the need to harness and integrate wind energy into the country’s energy mix for reliable power supply is what this work advocates.

Evaluating the wind energy potential for power generation requires a site-specific study [8]. Successful wind power development projects hinge on quality wind resource assessments and understanding of the variables affecting the wind resource. Wind power is strongly influenced by the wind resource behavior that fluctuates with a host of variables including topology, altitude and other meteorological parameters. A precise knowledge of wind energy regime is a pre-requisite for the efficient planning and implementation of any wind energy project. Knowledge of the statistical properties of the wind speed is essential for predicting the energy output of a wind energy conversion system. Although the concept of wind energy potential assessments has matured considerably, surprisingly, there seems to be limited application and adoption in regions of energy crisis where electricity demand far exceeds supply and are the ones in dire need of energy access as observed in [8].

Several studies have been reported on wind performance analysis across various locations in the world [8-17]. These studies are useful in understanding the diverse approaches that may be used to perform the analysis of different wind regimes. For example, to estimate frequency of wind speed curve, [18-19] noted that several probability density functions like Weibull distribution function, Rayleigh function, beta function, gamma function, lognormal function, and logistical function could be used. Similarly, it was observed by [9] that for all the analysis, the main tools used are the wind speed probability distributions and the functions representing them mathematically. In all of these, the Weibull function has been observed by several authors to show an acceptable distribution function that accurately fit the wind speed frequency in the given duration course leading to the conclusion that it is the most popular and best probability distribution for wind speed studies [9, 18, 20]. This study therefore aims to evaluate the wind power potential in the three major coastal communities of Akwa Ibom State, Nigeria and also determine the weibull parameters. Also, besides filling the knowledge gap, the result is intended to continue to emphasize the viability of commercial wind power development in such communities.

2. NIGERIA CLIMATE

The Nigeria with a current population of 185,000,000 [3], is popularly called the giant of Africa. It is situated in the western part of the continent and located within the geographical coordinates of 10°00’ N and 8°00’ E. It shares boundaries with Chad and Niger to the North, while to the West and East is Benin and Cameroon respectively as seen in Figure 1. Nigeria has basically two major seasons namely; the dry and rainy seasons. The former is observed to occur between November to March while the later usually occurs between April to October. Due to the vast nature of the country, these seasons vary slightly across the six geopolitical zones with some experiencing either shorter periods of rains and longer periods of sun or vice versa. During the dry seasons, the Northern part of the country often experience extreme high temperatures while the southern part of the country experiences frequent rains during the rainy seasons. The annual rainfall is about 200-400 cm in the southern tropical belt, 50-150 cm in the central regions and less than 50 cm in the North. The vegetation belts are made up of Mangrove swamps, rain forest, woodland savannah and the Guinea and Sudan Savannah [21].

Figure 1. Map of Nigeria indicating geographical coordinates (www.theodora.com/maps)

3. WIND ENERGY STATUS AND ITS ASSESSMENT IN NIGERIA

The need for environmental sustainability has continued to propel the growth of global wind power capacity and many countries are fast getting on board. For instance, in 2016, the total global installed wind capacity was nearly 487 GW which represents a cumulative market growth of over 12 percent with China still taking the lead. At the end of 2016, the global wind power industry installed 54.6 GW. Again, just within the first half of 2017, it has been reported that over 6 GW of wind energy capacity was added in Europe. Also, the wind market saw an addition of over 3.8 GW in new capacity by the end of June 2017, taking the cumulative installed capacity to 32.5 GW [22].

Several studies have been carried out to assess the wind energy situation in Nigeria [8, 23-25]. Resulting from such studies, it was observed that the wind energy potential varies with wind speed across the various regions of the country as can be spotted in Figure 2. Also, the studies indicated that resulting from the seasonal rain-bearing westerly winds between April and October and strong North-East trade winds from November to March, the country experiences strong winds. Generally, the country’s wind speed according to the studies ranges from about 2 to 12.5 m/s [23, 25]. Further analysis reveals that the South with exception of Enugu experience low wind speed regime while most parts of the North and some parts of the South West have high wind speed regime. Specifically, the North-West has the highest wind speeds ranging from 3.88 to 9.39 m/s at Yelwa and Kano respectively. In the North-East region, Jos, in Plateau State records a wind speed of 9.47 m/s [8, 23-25]. Other potential areas of very promising wind speed regime are along the country’s coastal lines. One of such areas is the study location of this work.

Despite the impressive wind speed regime recorded in most parts of the North resulting from the mountainous topography, development of wind energy generation system has suffered a similar fate to that of the country's power sector. Although some major initiatives have either been proposed and is at various stages of development, Nigeria is yet to witness an appreciable wind energy penetration.

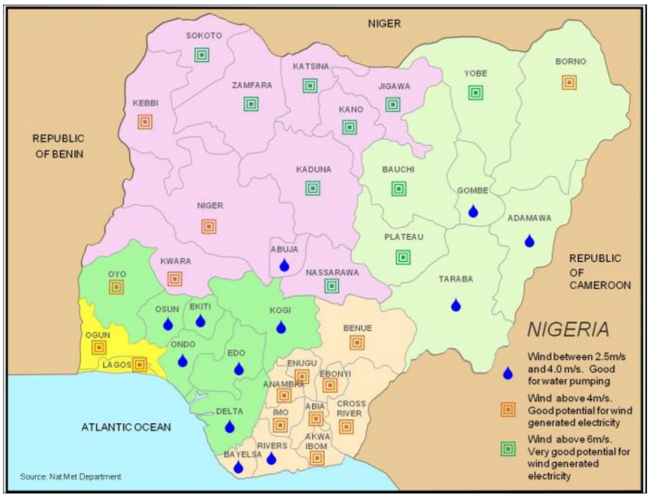

Figure 2. Wind Speeds across Nigerian States (Source: Nigeria Energy, Wind Power)

4. SITE DESCRIPTION AND DATA COLLECTION

The coastal belt of the Akwa Ibom state lies along the Atlantic Ocean. This provides great opportunity for offshore wind turbines. Akwa Ibom is currently the highest oil and gas producing state in Nigeria. It is a coastal state located in the popular Niger-Delta or South-South region of the country and lies between latitude 4°32'N and 5°33'N, and longitudes 7°25'E and 8°25'E. The state has a current population of over five million [3, 33] and is bordered on the east by Cross River State, on the west by River State and Abia and on the south by the Atlantic Ocean as seen in Figure 3. The state is home to two major seaports on the Atlantic Ocean and has recently proposed a world class seaport in Ibaka at Oron which is one of the study locations. The state also has an international airport, where some of the data used for this study were obtained. Since the state is situated along the country's coastal lines, the study was conducted using the three major coastal cities that boarders with the Atlantic Ocean namely: Ibeno, Oron and Okobo. Each of these coastal cities is described next.

Ibeno, a city in Akwa Ibom State occupies a vast coastal area of over 1,200 km^2. It lies in the Mangrove Forest Belt of the Niger Delta and on the eastern side of the Kwa Ibo River and is one of the largest fishing settlements on the Nigerian coast. The area is noted for rains throughout the year with peak between May and September. It is bounded to the south by the Atlantic Ocean which is one of the major reasons the site was chosen for this study. Lastly, the city is home to oil giant Exxon Mobil and other oil exploration companies.

Oron is another coastal city of the State and is home to the Maritime Academy of Nigeria. It is located in a tropical rainforest region and is noted to have a uniform high temperature throughout the year. The South-West onshore wind brings heavy rains while the North-East trade wind which blows across the Sahara desert ushers in the dry season. The city is situated on the flood plain of the Southern part of the country with a land mainly traversed by several streams and tributaries flowing into Cross River. The city is currently rated as having the highest supplies of natural gas deposits in Sub-Saharan Africa.

Okobo is a small coastal city located close to Oron and shares certain geographical features – like the tropical forest and plenty of small rivers. The state international airport is located in some part of this city hence the choice of the location for the study.

The daily wind speed data used in this study was obtained from the Nigeria Meteorological Agency (MIMET) for Ibeno (Latitude 4° 33' 54.2"N; Longitude 8° 4' 21.3"E) and Okobo (Latitude 4°41'48.48"N; Longitude 8°15'23.23"E), while that for Oron (Latitude 4°48'26.53"N; and Longitude 8°14'15.74"E) was obtained from Maritime Academy of Nigeria, Oron for a period of five years (2012 - 2016). The wind speed data was measured continuously with an Anemometer at a height of 10m. The data obtained provides daily average wind speed distributions of the location for the stated period from which average values were computed. Using the two-parameter Weibull function, the frequency distribution of the measured data was studied.

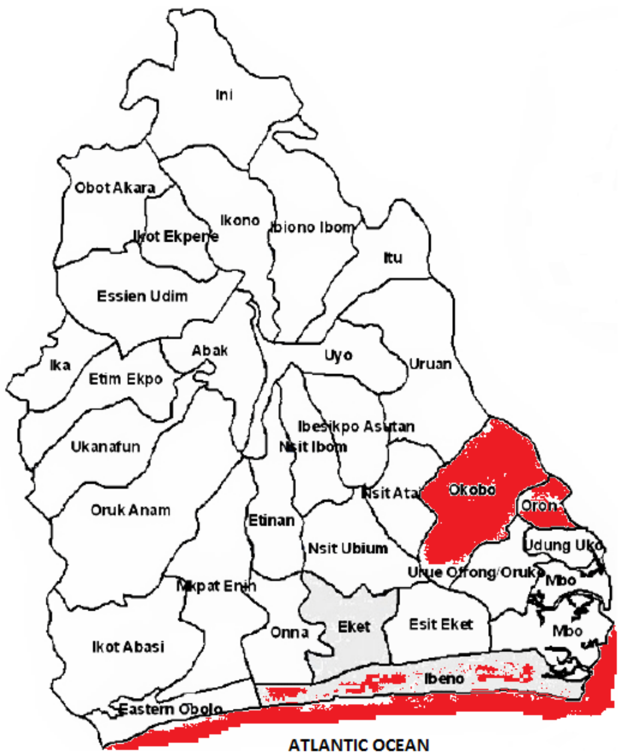

Figure 3. Map of Akwa Ibom State indicating the study locations

5. ANALYSIS PROCEDURE

Using data obtained from the Nigeria Meteorological Agency (MIMET) and the Maritime Academy of Nigeria, Oron for Ibeno, Okobo and Oron respectively for a period of five years (2012-2016), a statistical analysis was performed.

5.1 Weibull Probability Density Function

Calculating the mean power delivered by a wind turbine from its power curve requires the knowledge of the probability density distribution of the wind speed which is simply the distribution of the proportion of time spent by the wind within narrow bands of wind speed. In statistical modeling of wind speed variation, the Weibull two-parameter (shape parameter k and scale parameter c) function has been widely applied by many researchers. The probability density function of the Weibull distribution is given by [26] as:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (1)$$

where $f(v)$ is the probability of observing wind speed v, k is the dimensionless Weibull shape parameter and c is the Weibull scale parameter, which have reference values in the units of wind speed. These two parameters (k & c), characterize the wind potential of the area under study. While the scale parameter c, indicates how 'windy' a location is, the shape parameter k, shows how peaked the wind distribution is (i.e. a high value of k is observed if the wind speeds tend to be very close to a certain value).

The corresponding cumulative probability function of the Weibull distribution is expressed by [26-27] as:

$$F(v) = 1 - exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (2)$$

where v is the wind speed, k is the shape parameter and c is the scale parameter. Here, $f(v)$ represents the fraction of time (or probability) for which the wind blows with a velocity V, and $F(v)$ indicates the fraction of time (or probability) that the wind velocity is equal or lower than V [28].

From eqn. (1) and (2) it is evident that k and c are the factor affecting the wind spectra within a given regime. The shape and scale parameter k and c are measured using empirical method by the following equations [28]:

$$k = \left(\frac{\sigma}{\overline{V_m}}\right)^{-1.086} \quad (3)$$

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (4)$$

$$\Gamma(x) = \int_0^\infty t^{x-1} e^{-t}\, dt \quad (5)$$

$$\Gamma(x) = \sqrt{2\pi x}.\, x^{x-1}.\, e^{-x}.\left(1 + \frac{1}{12}x + \frac{1}{288}x^2 - \frac{139}{58140}x^3 + \cdots\right) \quad (6)$$

Shape and scale parameters in this method are estimated from the mean wind speed (V_m) and standard deviation (σ) of wind data.

5.2 Wind Power Density

The Wind Power density measured in W/m^2 indicates how much energy is available at the site for conversion by a wind turbine. The power of the wind that flows at speed v through a blade swept area A, increases with the cube of the wind and the area, thus;

$$\frac{1}{2}\rho V^3 \quad (7)$$

where ρ is the standard air density at sea level with a mean temperature of 15ºC and a pressure of 1 atm (1.225 kg/m^3) and V is the mean wind speed (m/s).

The expression is dependent on the air density and the wind speed but independent of the size of the turbine rotor or the efficiency or other characteristics of the wind turbine [29].

5.3 Wind Annual Electricity Estimate

Using Equation (8), a rough estimate of the electricity production (in kilowatt hours per year) from a number of wind turbines at any site can be obtained if the mean annual wind speed is known [30]. Thus, annual electricity production is estimated using:

$$KV_m^3A_tT \quad (8)$$

where K = 3.2 and a factor based on typical turbine performance characteristics and an approximate relationship between mean wind speed and wind speed frequency distribution.

V_m = the site annual mean wind speed in ms^{-1}, A_t is the swept area of the turbine in m^2, T is the number of turbines.

5.4 Wind Available Power

According to [31], the extracted power from the wind is given by:

$$\frac{1}{2}\rho A V^3 C_p \quad (9)$$

where P_{avail} is the Available Power in the wind, ρ is the Air density (1.225 kg/m^3), A is the swept Area of the turbine given by: $A = \pi r^2$; Where radius, r is equal to the blade length. The rotor diameter is related to the blade length and the swept area. Thus; $\text{Rotor diameter}/_2 = \text{Blade length}$; $\text{Blade length}^2 * \pi = \text{Swept area}$. Doubling the swept area means doubling the power output. However, if the wind speed doubles then the power output increases by a factor of 8, which simply means producing 8 times more power; V is the mean wind speed, and C_p is the Power coefficient given by 0.59.

5.5 Wind Annual Energy Output

Annual energy output (AEO) is given by [32] to be;

$$\text{AEO} = \frac{1}{2}\rho A V^3 C_p (8{,}760 hrs/year) \quad (10)$$

6. RESULTS AND DISCUSSION

In this study, wind speed data for three coastal locations in Akwa Ibom State, Nigeria for a period of five-years (2012 to 2016) were analyzed using Microsoft Excel and Wind Energy Calculator – an android application developed by the authors using android studio. The application prompts for certain input from the user and does the computation using Equations (7) to (10) and other related parameters. Specifically, the application was used for the determination of wind power density, annual electricity production and the available wind power while empirical method was employed for the determination of Weibull distribution parameters in terms of k and c and the mean wind speed. The various results obtained is presented in Tables, graphs & chats and discussed as follows.

6.1 Wind Pattern

6.1.1 Monthly mean wind speeds

The monthly average wind speed variation across the three locations for the period of the study is captured in Figure 4a and 4b. By inspection, it is observed that the wind speed variation of Ibeno clearly exceeds that of the other two locations and this is consistent all through the years. Also, still considering Ibeno, it is noticed that consistently, the wind variation is at its peak between the months of March and September which falls during the rainy season period of the country. This pattern is also noticed for the other two locations indicating that variation in wind speed is greater during the rainy season compared to the dry season. The monthly mean wind speed and yearly standard deviation for the three locations is presented in Tables 1 to 3.

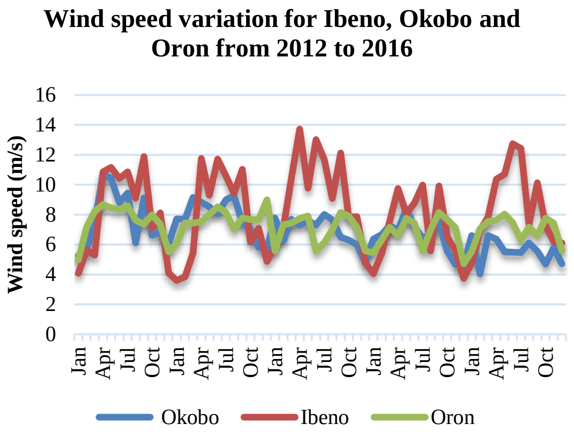

Figure 4(a). Average monthly wind speed variation across the three locations from 2012 to 2016.

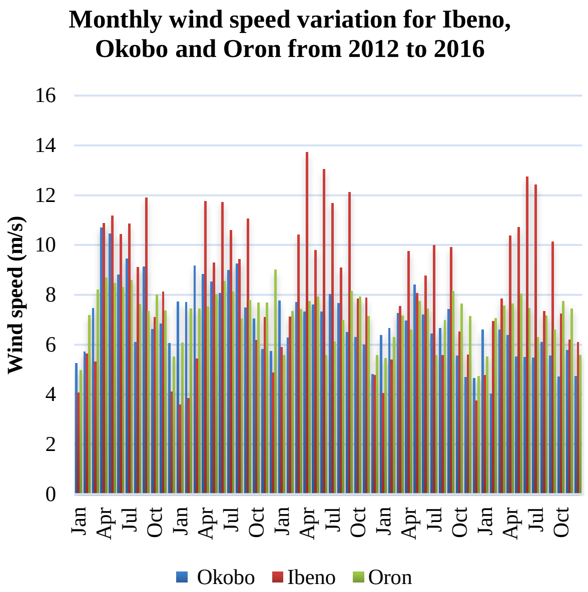

Figure 4(b). Monthly wind speed variation across the three locations from 2012 to 2016.

From table 1-3, it is seen that there is a similarity in the monthly mean wind pattern across the three coastal locations for the different years. Noticeably, the average wind speed values are quite impressive across the three locations with that of Ibeno being outstanding. Averagely, most of the monthly mean wind values fall between 8.00 and 11.80 m/s. clearly, these high values indicate good potentials for wind power development along these coastal regions. Again, most of the high monthly mean wind speed values are observed between April and September across the three locations while the low monthly mean values are observed between November and January. For instance, the highest mean wind speed values of 13.73 m/s, 8.68 m/s, 10.70 m/s were observed in April 2014, April 2012 and April 2012 for Ibeno, Oron and Okobo respectively while the lowest mean wind speed values of 3.59 m/s, 4.73 m/s, 1.36 m/s were observed in January 2013, December 2015 and August 2014 respectively. The highest standard deviation value of 2.95 m/s for Ibeno was in 2013 while the least value of 2.15 m/s still for Ibeno was in 2015. For Oron, the highest value of 1.13 m/s was in 2012 while the least value of 0.70 m/s was in 2013. The highest for Okobo was 1.76 m/s in 2014 while the least of 0.67 m/s was in 2016. The highest and lowest mean wind speed values and corresponding months for which this occurred for each year across the three locations is illustrated in Table 4 (a) and Table (b) respectively.

Table 1. Monthly average wind speeds and yearly standard deviation for Ibeno.

Month	Parameter	2012	2013	2014	2015	2016
Jan.	Average wind speed(v)	4.073	3.595	5.890	4.057	4.781
Feb.		5.645	3.841	7.121	5.400	6.936
Mar.		5.304	5.429	10.414	7.547	7.850
April		10.867	11.763	13.729	9.742	10.365
May		11.172	9.296	9.782	8.064	10.717
June		10.423	11.723	13.036	8.762	12.744
July		10.860	10.594	11.687	9.994	12.422
Aug.		9.108	9.426	9.082	5.577	7.338
Sept.		11.899	11.045	12.126	9.912	10.137
Oct.		7.095	6.186	7.837	6.525	7.249
Nov.		8.129	7.095	7.875	5.597	6.190
Dec.		4.101	4.872	4.781	3.743	6.105
	Standard deviation(σ)	2.775	2.955	2.73	2.15	2.501

Table 2. Monthly average wind speeds and yearly standard deviation for Oron.

Month	Parameter	2012	2013	2014	2015	2016
Jan.	Average wind speed(v)	4.972	6.070	5.582	5.456	5.520
Feb.		7.176	7.432	7.341	6.306	7.064
Mar.		8.200	7.432	7.429	7.157	7.555
April		8.682	7.527	7.744	6.602	7.639
May		8.465	8.011	7.917	7.753	8.036
June		8.314	8.539	5.583	7.443	7.470
July		8.592	8.117	6.126	5.583	6.306
Aug.		7.627	7.041	6.986	6.986	7.157
Sept.		7.348	7.778	8.15	8.150	6.602
Oct.		7.996	7.676	7.917	7.644	7.753
Nov.		7.356	7.676	7.132	7.132	7.443
Dec.		5.517	5.999	5.583	4.730	5.583
	Standard deviation(σ)	1.133	0.703	0.941	0.997	0.825

Table 3. Monthly average wind speeds and yearly standard deviation for Okobo.

Month	Parameter	2012	2013	2014	2015	2016
Jan.	Average wind speed (v)	5.258	7.699	6.275	6.661	4.034
Feb.		5.710	9.159	7.699	7.262	6.604
Mar.		7.468	8.82	7.319	6.964	6.378
April		10.701	8.527	7.596	8.398	5.515
May		10.444	8.059	7.314	7.201	5.499
June		8.815	8.995	8.023	6.440	5.474
July		9.457	9.252	7.663	6.651	6.106
Aug.		6.106	7.488	1.356	7.427	5.546
Sept.		9.123	7.046	6.296	5.561	4.708
Oct.		6.62	5.818	5.993	4.682	5.782
Nov.		6.836	5.731	4.805	4.651	4.728
Dec.		6.049	7.771	6.373	6.594	5.345
	Standard deviation(σ)	1.755	1.149	1.760	1.056	0.669

Table 4 (a). Highest and lowest mean wind speeds values and corresponding months across the three locations (2012 to 2014).

	2012				2013				2014			
	Highest		Lowest		Highest		Lowest		Highest		Lowest	
Locatn.	Mth.	Avg.	Mth.	Avg.	Mth.	Avg.	Mth.	Avg.	Mth.	Avg.	Mth.	Avg.
Ibeno	May	11.172	Jan.	4.073	Apr.	11.76	Jan.	3.595	Apr.	13.729	Dec.	4.781
Oron	Apr.	8.682	Jan.	4.972	June	8.539	Dec.	5.999	Sept.	8.15	Jan.	5.582
Okobo	Apr.	10.701	Jan.	5.258	July	9.252	Nov.	5.731	June	8.023	Aug.	1.356

Table 4 (b). Highest and lowest mean wind speeds values and corresponding months across the three locations (2015 to 2016).

Locatn.	2015				2016			
	Highest		Lowest		Highest		Lowest	
	Mth.	Avg.	Mth.	Avg.	Mth.	Avg.	Mth.	Avg.
Ibeno	July	9.994	Dec.	3.743	Apr.	12.74	Jan.	4.781
Oron	Sept.	8.15	Dec.	4.73	June	8.036	Dec.	5.52
Okobo	Apr.	8.398	Nov.	4.651	July	6.604	Nov.	4.034

6.1.2. Yearly mean wind speeds

The yearly wind speed variation for the three locations from 2012 to 2016 is presented in figures 5 to 7. For each location, the annual mean wind speed is obtained by averaging the wind speed for each year. For all the locations, the results indicate that the mean wind speed is greater than 6.0 m/s. Specifically, from Table 5, Ibeno records an average of 8.24 m/s over the five-year period while Oron and Okobo records 7.26 and 6.70 m/s respectively. For Ibeno, the highest mean wind speed occurred in 2014 while the least was recorded in 2015. For Oron and Okobo, the highest mean wind speed occurred in 2013 & 2012 while the least was recorded in 2015 & 2016 respectively. Inferring from the wind classification of Figure 2, it can be concluded that all three locations have very good potential for wind generated electricity. This further implies that the locations under consideration are very suitable for deployment of large-scale wind turbine systems for all year-round electricity generation.

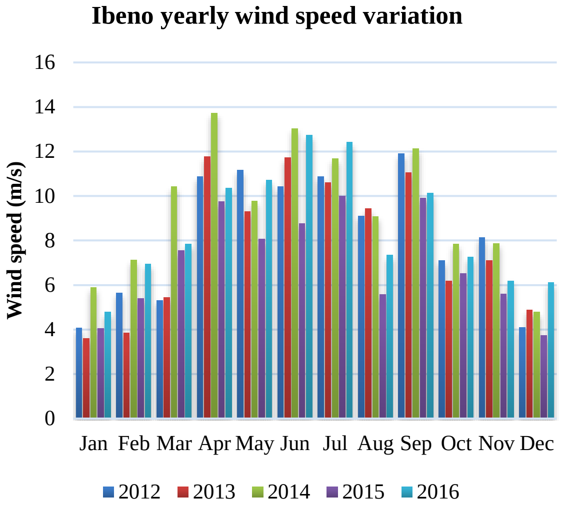

Figure 5. Yearly wind speed variation for Ibeno from 2012 to 2016.

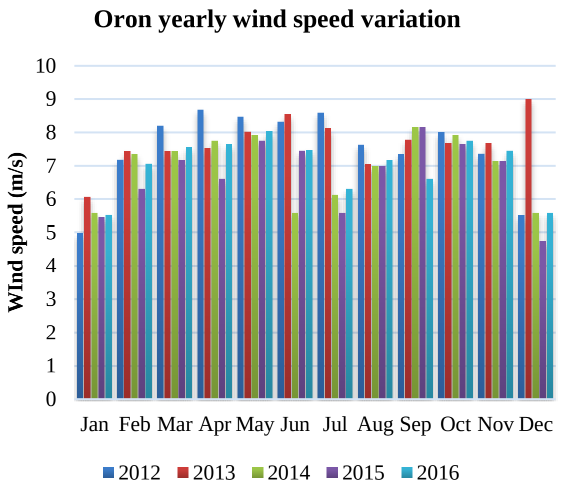

Figure 6. Yearly wind speed variation for Oron from 2012 to 2016.

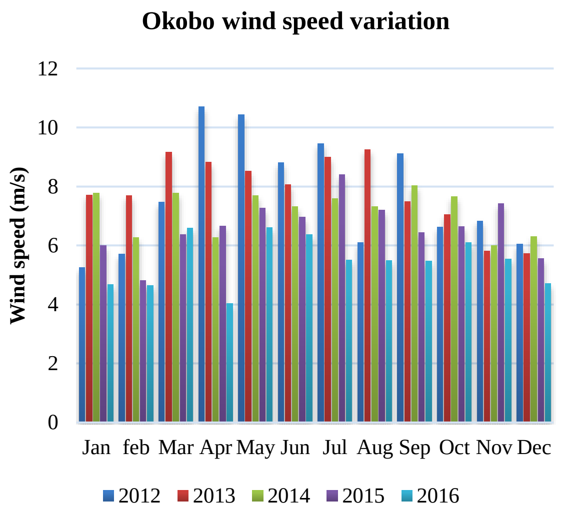

Figure 7. Yearly wind speed variation for Okobo from 2012 to 2016.

6.1.3. Seasonal wind speed variation

The seasonal variation using average wind speed for each season is shown in Figures 8 to 10. The wind pattern for each season is similar across the three locations. It is observed that the wind speed is relatively high throughout the rainy season and still maintains an averagely good value during the dry season. The average values of 11.5 & 6.0 m/s, 8.0 & 6.4 m/s and 8.2 & 5.8 m/s for rainy and dry seasons for Ibeno, Oron and Okobo respectively were recorded. Again, this result reiterates the promising potential of an all year-round wind generated electricity along those coastal sites.

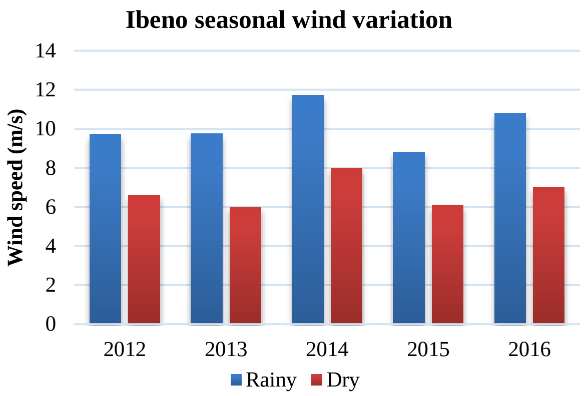

Figure 8. Seasonal wind speed variation for Ibeno from 2012 to 2016

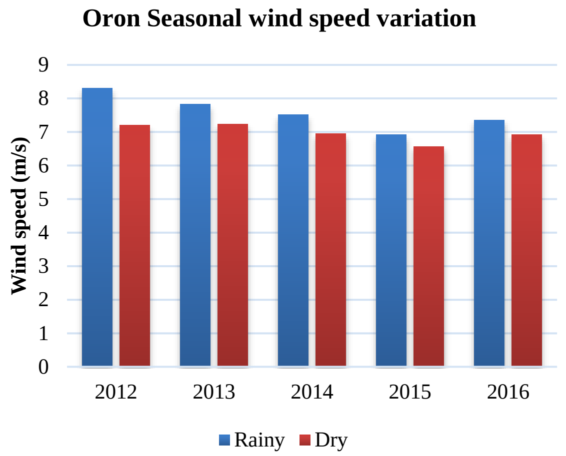

Figure 9. Seasonal wind speed variation for Oron from 2012 to 2016

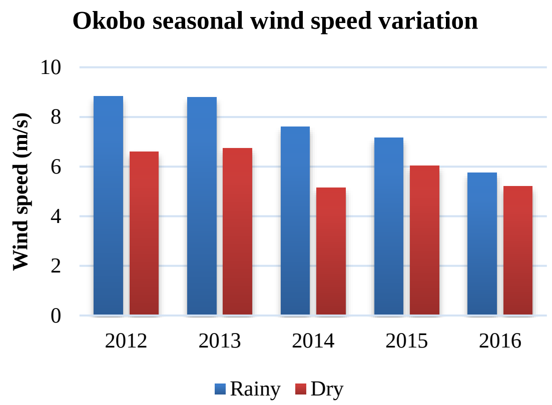

Figure 10. Seasonal wind speed variation for Okobo from 2012 to 2016.

6.2. Weibull distribution

In Table 5, the overall average values of wind speed, standard deviation, shape parameter (k), scale parameter (c), Weibull cumulative distribution and Weibull probability density functions for five years (2012 to 2016) is presented. The values of k and c were determined using the empirical method described earlier. The K parameter indicates how peak the wind speed at the study locations are. For Ibeno, Oron and Okobo, the average k values were 3.29, 4.74 and 4.11 respectively indicating that the entire site had a seemingly even wind spread. On the other hand, the C parameter indicates how windy the site is. Thus, Ibeno was observed to be the windiest followed by Oron and Okobo with values of 7.72, 6.54 and 6.40 m/s respectively. The average values of the Weibull cumulative distribution and Weibull probability density functions were also seen to be close across all three locations.

Table 5: Overall average wind speed, standard deviation, shape & scale parameters and Weibull functions.

Location	Average wind speed (m/s)	Standard deviation(σ)	k (Shape parameter)	c (Scale parameter) (m/s)	Weibull cumulative Distribution function	Weibull probability Density function
Ibeno	8.24	2.74	3.29	7.72	0.71	0.14
Oron	7.26	2.81	4.74	6.54	0.72	0.13
Okobo	6.70	1.82	4.11	6.40	0.70	0.22

6.3. Calculation of wind power density and energy

Using the Wind Energy Calculator – an android application developed by the authors, the wind power density, annual electricity production and the available wind power were determined and presented in Table 6. In determining the wind power density using the application, the average wind speed value and air density for the various locations are inputted. Also, for the available power, the former parameters along with the turbine blade length are inputted. Lastly, for the annual electricity production, the average wind speed, turbine blade length and required number of turbines are also inputted. Cleary, from the five-year average, Ibeno had the highest followed by Oron and Okobo respectively in all the parameters evaluated.

Similarly, results for the annual electricity production during the rainy and dry seasons for all the locations are presented in Table 7. Again, across all locations, the predictions were quite high during the rainy season compared to the dry season. It is also note-worthy to observe that even during the dry season, the predictions were equally impressive which goes a long way to reaffirm the viability of an all year-round wind electricity generation.

7. CONCLUSION

The wind potential across three coastal cities - Ibeno, Oron and Okobo in Akwa Ibom State, Nigeria was investigated. The statistical analysis was performed using data obtained from the Nigeria Meteorological Agency (MIMET) and the Maritime Academy of Nigeria, Oron for Ibeno, Okobo and Oron respectively for a period of five years (2012-2016). The Weibull distribution parameters in terms of k and c were determined using empirical method, while the wind power density, annual electricity production and the available wind power were obtained using the wind energy calculator – an android application developed by the authors for wind power calculation. The Overall average power density and mean wind speed were determined for the three locations to be 344.68, 236.10 & 185.18 w/m^2 and 8.24, 7.26 & 6.70 m/s respectively for the study duration. The results indicate that all the locations had a wind speed range higher than the 5-6 m/s recommended for electricity generation and a wind density value greater than 100 W/m^2, as such would be a perfect site for large-scale wind power development. Noticeably, for all locations, the average wind speed was greater during the rainy season months with overall average values of 11.5, 8.0 and 8.2 m/s for Ibeno, Oron and Okobo respectively. Averagely, the maximum monthly wind speed occurs between the months of April and June, while the months of December and January have the lowest mean wind speed. Resulting from the analysis, the annual electricity generation was projected for all locations, leading to the conclusion that the three cities located along the coastal lines of Akwa Ibom, would be a viable site for commercial wind power production.

Table 6. Overall average energy production predictions for the three locations.

Location	Wind power density(W/m^2)	Available power (MW)	Annual energy production (GW)
Ibeno	344.68	1.73	15.23
Oron	236.10	1.18	10.45
Okobo	185.18	0.93	8.19

Table 7. Overall average electricity production during the seasonal variation.

Yearly electricity production(kWh/yr)	Ibeno		Okobo		Oron	
	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season
2012	25.01	7.84	18.73	7.81	15.62	10.14
2013	25.28	5.89	18.54	8.34	13.08	10.32
2014	43.87	13.95	11.95	3.69	11.56	9.13
2015	18.67	6.21	9.95	5.99	9.01	7.71
2016	34.44	9.47	5.18	3.82	10.84	9.01

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