A REVIEIW OF WIND ENERGY POTENTIAL IN KANO STATE, NIGERIA FOR THE PURPOSE OF ELECTRICITY GENERATION

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Abstract - *This paper reviews the wind energy potential in Kano for the purpose of electricity generation. With the fast development of non-renewable energy source cost and resulting thought of depleting non-sustainable energy sources, the consideration of designers, researchers and engineers have centers in advancing renewable energy sources. The power yield from a wind turbine is emphatically subject to the wind speed and accurate data about the wind information in the targeted location. The wind speeds in Kano went from about 4.3 to 9.39 m/s as reported by many researchers in the field. These results indicated that wind speeds at Kano are reasonable for wind energy generation. Wind speed variation, power and energy in wind are also presented. Also some of the issues in the papers used in this study and suggested solutions were presented. In addition, conclusion and recommendations were also presented for further studies.*

Key Words: **Wind energy, Wind speed, Kano, Power density, Electricity**

1. INTRODUCTION

Wind energy has been utilized since the most punctual human advancement to grind grain, pump water from a deep well and power boats. With the ongoing flood of petroleum product costs, interest for cleaner energy sources, and government subsidizing motivations, wind turbines have turned out to be suitable innovation for power generation, because the use of wind energy has been expanding around the world at an accelerating pace. The major contribution of this study is the classification of the literature based on wind speed and energy potential analysis. The wind speed is the most important information required in the estimation of wind energy potentials of a location. Wind is intermittent because it is driven by weather systems. It is also influenced by local terrain and height above the ground level. Proper assessment of a station requires long term data of about 10 years or more [1]. By and large wind energy is characterized by a high variability both in space and time. It is therefore vital to analyze the variation in wind speeds for design optimization of the system so as to reduce the cost of generating the energy [2]. In spite of the benefits of utilizing wind and high wind energy potential, it generates just 1.4% of the world's electric power [3]. A wind turbine converts the kinetic energy in wind into mechanical energy and electric generator converts the mechanical energy to electrical energy. The wind turbine is normally coupled with shaft and gearbox so as to match the low speed rotation of the turbine's rotor with high speed rotation of the generator. The system consists of rotor, the generator and other associated parts are more commonly referred to as Wind Energy Conversion System (WECS) [4, 26]. Wind turbines used to produce electricity come in different configuration and sizes. Large wind turbines may generate many hundred mega Watts of power, adequate enough to power several homes. Small wind turbines, which are commonly designed to generate not in excess of 100 KW of power, are usually introduced at houses, farms, and small scale businesses either as a backup or as main source of power in order to reduce electricity bills [5, 17]. In 1974, NASA constructed and operated a wind generator of 100kW capacity with 38m diameter rotor installed over a 30m height tower. Success encouraged the US firms to manufacture a 2.5 MW generator in 1987[5, 16, 18-19]

The study considers Kano because of its huge industrial base and it is a commercial center in the country.

The wind energy potential studies for Kano have been conducted by many researchers; the results are known but not many critical reviews of these studies have been carried out especially for Kano. This study provides a critical review on wind energy prospects in Kano based on available published papers and can serve as a basis for wind energy resource assessment. The significance of this work is that it reviews the wind energy potentials of the study area and presents researchers, investors and government with required information for wind energy assessment, investment in wind energy systems and energy policy formulation, among others.

2. THEORETICAL FUNDAMENTALS

The estimation of wind energy potential is based on the following methods:

- Wind data of a specific site using frequency distribution.
- The type of wind energy generator

- Weibull factors of the wind data and
- WEGs characteristics.

2.1.1 Mean wind speed

Mean wind speed (MWS) is most commonly used indicator of wind speed production potential. The mean wind speed is defined as:

$$MWS = \frac{1}{N}\sum_{i-1}^{i-N} v_i \text{.............} (1)$$

Where N is the sample size and v_i is the speed recorded for i[th] observation.

2.1.2 Wind speed variation with height

Wind speed near the ground changes with height. This requires an equation that predicts the wind speed at one height in terms of the measured speed at another. The most common expression for variation of wind speed with height is the power law having the following form [6]:

$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^{\propto} \text{................} (2)$$

Where v_2 and v_1 are the mean wind speeds at heights h_2 and h_1, respectively. The exponent $\propto$ depends on factors such as surface roughness and atmospheric stability. Numerically, it lies in the range 0.05-0.5, with the most frequently adopted value being 0.14 which is widely applicable to low surface and well exposed sites.

2.1.3 Wind power density function

It is well known that the power of the wind at speed (v) through a blade sweep area (A) increases as the cube of its velocity and is given by the following equation [15]:

$$P(v) = \frac{1}{2}\rho A\ V^3 \text{.....................} (3)$$

Where ρ is the mean air density (1.225 kg/m^3 at an average atmospheric pressure at sea level and at 15°C), which depends on altitude, air pressure, and temperature.

The expected monthly or annual wind power density per unit area of a site based on a Weibull probability density function can be expressed as follows [6]:

$$P_w = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) \text{... ... ...} (4)$$

Where C is the Weibull scale parameter (m/s) and is given by [6]:

$$C = \frac{V_M}{\Gamma\left(1+\frac{3}{k}\right)} \text{.......................................} (5)$$

The two significant parameter $\boldsymbol{k}$ and $\boldsymbol{c}$ are closely related to the mean value of the wind speed V_M.

By extracting $\boldsymbol{c}$ from equation (5) and setting $\boldsymbol{k}$ equal to 2, the power density for the Rayleigh model is found to be [6],

$$P_R = \frac{3}{\pi}\rho V_m^3 \text{.........................} (6)$$

Knowing the value of Wind Power Density, Wind Energy Density can be determined; wind energy density can be estimated by the time factor as wind power density is known. It can be defined as [6]:

$$WED = WPD^* A^* T^* Cp \text{........................} (7)$$

T is the time which can be 8760 hours per year. WED depends on the efficiency of the wind turbine (power coefficient, Cp) and the swept area, A. The value of power coefficient is unique to each turbine type and is a function of wind speed that turbine is operating in. The real world limit is well below the Betz Limit with values of 0.35-0.45 common even in the best designed wind turbines. Transferred energy from wind into wind turbine can be calculated through the equation [6]:

$$P_W = 0.5\rho_a C_p V_w^3 A \text{ ... ...} (8)$$

Where P_W is the transferred power from the wind to the wind turbine in watts, ρ_a is the air density (kg/m^3), V_w is wind speed (m/s), C_p is the power factor based on the Betz limit which is the maximum energy is terminated to 59.3%.

2.2 WIND SPEED DISTRIBUTION

To determine the wind energy potential in particular sites detailed knowledge of wind speed distribution is the most crucial factor.

From the literature, it is observed that different wind speed distribution models are available in fitting the distribution of wind, namely Rayleigh distribution, Gamma distribution, 2-parameter Weibull distribution, 3-parameter Weibull distribution, Pearson distribution, Lognormal distribution, Farahet distribution and Gumbe I distribution. In modeling wind speed, Weibull distribution model is the most widely used in literature and the only recommended model in wind energy books, but the reliability of Weibull model depends on the accuracy in estimating of the parameters. The Weibull probability and cumulative distribution model is given by [7]:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} exp\left\{-\left(\frac{v}{c}\right)\right\}^k \text{ ... ...} (9)$$

$$F(v) = exp\left\{-\left(\frac{v}{c}\right)\right\}^k \ldots\ldots\ldots (10)$$

Where c is the Weibull scale parameter in m/s, a measure for the characteristic wind speed of the distribution, c is proportional to the mean wind speed. K is the Weibull shape parameter which has no unit. It specifies the shape of a Weibull distribution and takes on a value of between 1 and 3. A small value for k signifies very variable winds, while constant winds are characterized by a larger k. But according to past studies, where there is insufficient data about the frequency distribution of the wind speed at a particular location, the cumulative distribution function can be best described as [7]:

$$F(v) = 1 - exp\left\{-\left(\frac{v}{c}\right)\right\}^k \ldots\ldots (11)$$

At present the 2-parameter Weibull distribution function is accepted as the best all over the world. Many researchers used above mentioned model in wind speed calculation due to high level of accuracy and provides better fit to probability distribution compared with other models.

There are several methods in estimating the Weibull parameters among others are least square method (Weibull Graphical Probability Plotting), method of moments, Maximum Likelihood Method (MLM), Modified Maximum Likelihood Method (MMLM), Standard Deviation Method (SDM) and Power Method (PM).

The accuracy of each method mentioned above can be determined using suitable methods; the following statistical indexes of accuracy are employed [6]:

$$RMSE = \left[\frac{1}{N} \cdot \sum_{I=1}^{N} (y_i - x_i)^2\right]^{1/2} \ldots\ldots (12)$$

$$x^2 = \frac{\sum_{i=1}^{N} (y_i - x_i)^2}{x_i} \ldots\ldots (13)$$

$$R^2 = \frac{\sum_{i=1}^{N} (y_i - \bar{y}_i)^2 - \sum_{i=1}^{N} (y_i - \bar{x}_i)^2}{\sum_{i=1}^{N} (y_i - \bar{y}_i)^2} (14)$$

$$KOL = Max\,|Fn\,(v) - F_n\,(v)| \ldots (15)$$

3. WIND ENERGY POTENTIAL IN KANO

3.1 Previous wind energy potential studies

At present, there have been studies carried out related to wind energy potential in the location.

Ahmed *et al* [8] have analyzed a seventeen years (1990-2006) wind speed data in six selected locations in Nigeria including Kano state, measured using cup anemometer installed at height of 10m from the ground level. Their results indicated that, the sites are good locations for wind potential in electricity generation from wind; the study also shows that the highest wind power density occurred in Kano as 1219W/m^2 in the month of April.

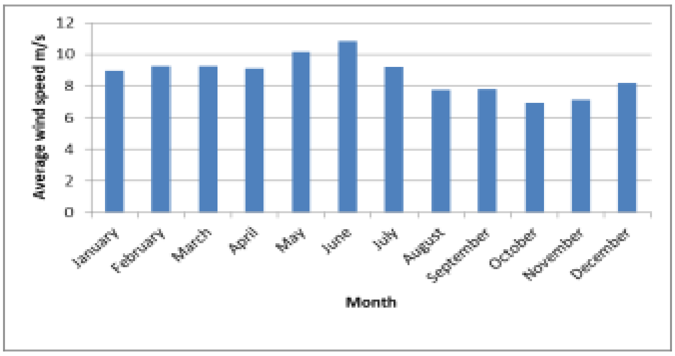

Chart 1: Average wind speeds(m/s) at 10m height [8]

In terms of wind energy potential for Northwestern Nigeria, studies have been conducted. [9], has assessed wind energy potential at heights of between 30m and 80m for period of fifteen years using the Reliasoft Weibull ++ 7 software and wind power calculator for Northwestern Nigeria. According to the results shows that only three locations (Sokoto, Kano and Gusau) indicate very reasonable potential at these heights. At 10m height, the mean annual wind speed for Kano is 4.53m/s and mean annual power densities at selected hub heights of 30, 40, 50, 60, 70 and 80m are: 113.23, 140.50, 166.09, 190.43, 213.77 and 236.29W/m^2.

Table 1: Mean annual power densities at various hub heights

Heights	P_{30}	P_{40}	P_{50}	P_{60}	P_{70}	P_{80}
Power densities (W/m^2)	113.23	140.50	166.09	190.43	213.77	236.29

[10]In addition to that, same author conducted a study on wind electricity generation for selected regions in Northwestern Nigeria. The analysis showed that Kano's wind speed regime at the hub heights fall in class 5 and thus the site could be utilized for large-scale wind plants. Kano has the highest mean annual wind energy production for the three models (1292, 1034 and 4979MWh/year respectively). Using Vestas 2000/80 as a model wind turbine based on 25% of total power demand for Kano, a wind farm scheme shows good promise.

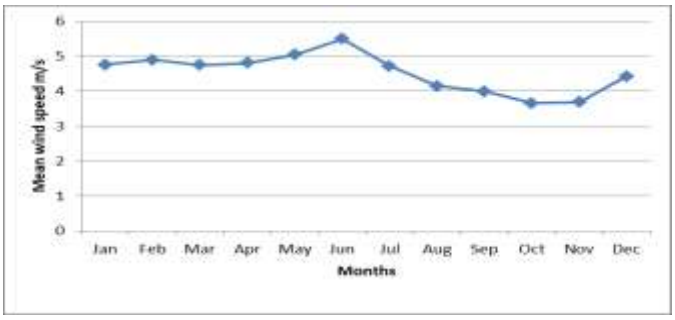

Chart 2: Monthly mean wind speeds(m/s) [10]

Besides that, a case study of the wind profile characteristics and turbine performance analysis in Kano, Northwestern Nigeria has likewise been conducted by Oluseyi *et al* [11], the paper assessed the electricity generation from wind at Kano, Nigeria. Twenty one years (1987-2007) monthly wind speed data at a height of 10m were analyzed and the data were subjected to different statistical tests and also validated with the two-parameter Weibull probability density function. The result indicated that the average monthly wind speed ranged from 6.6 to 9.5m/s. Also calculated monthly wind power went about 3.6 and 12.5 MWh/m^2. Based on their study the results indicated that wind speeds at Kano may be economically viable for wind electricity generation at and above the height of 10m. In addition, five practical wind turbine models were analyzed for the site wind potential with result shows strong economic viability.

Table 2: Monthly mean wind speeds and Weibull parameters estimation for the entire period

Months	Jan.	Feb.	March	Apr	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
MWS (m/s)	8.2	8.7	8.4	8.9	9.1	9.6	8.9	7.6	7.4	6.6	6.8	7.9
C (m/s)	9.2	9.8	9.4	9.7	10.2	10.7	10.0	8.5	8.0	7.3	7.6	8.8
k	2.7	2.1	2.4	4.9	2.7	3.4	2.4	2.7	4.9	4.1	2.9	4.1

In the paper by [12], it discussed about the result of a study based on a collected wind data from the Meteorological Department, Climate Investigation Unit of the Federal Ministry of Aviation, Lagos, Nigeria. Ten years (1978-1988) monthly average of the wind data was collected. In his study the Weibull and the normal distribution functions were fitted onto a constructed histogram of the wind speed information of Kano and approved with some integrity of-fit tests. Likewise, appraisals of the wind accessibility and potential for utility-scale wind power production at the hub height of some chosen wind turbines were done. The study suggested that the wind speed distribution of Kano can be assumed Weibull or normally distributed with 5% significance level (95% confidence level). The distribution functions might be utilized to estimate with better precision the wind power potentials of the study site. The outcome demonstrates that with an FL30 turbine near half of its installed capacity can be harnessed and be running for practically 50% of the time it might be worked in a year. While other turbines like Vesta47 and NW100/19 were not found suitable for wind power generation in Kano. Conclusively, he suggested that a wind farm sited in Kano using FL30 turbines might add a tremendous amount of electrical energy to the grid system.

Adnan *et al* [13]. has presented their paper studies on the prospects of establishing wind turbine systems in Kano state, Nigeria. One year (2007) data was collected and analyzed from NIMET synoptic station in Kano state, located at Mallam Aminu Kano International Airport. The results indicated an average minimum wind speed of 3m/s for September and October and a maximum wind speed of 5.6m/s for June. The study also established an annual average wind speed of 4.3m/s over the year 2007 in the municipality and some rural areas of the study site. The result recorded in this research shows the major contributions of prevailing winds in the year were found out to be from South-west wind (56%) in May, East wind (52%) in January, and North-east wind (46%) in February. The South-west twist prevalently gave a noteworthy commitment from February to July over the year. According to the study, these findings prove the prospects of establishing small wind turbine system in the state. The researcher concluded that there are good opportunities of utilizing the available wind energy in Kano state and its rural areas for practical applications.

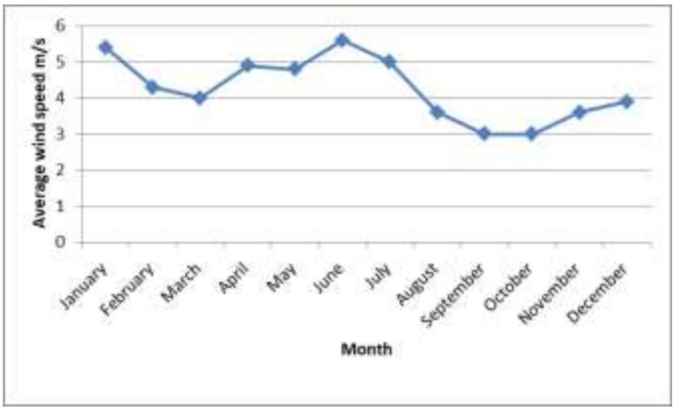

Chart 3: Average wind speeds(m/s) for 2007 [13]

Research by [14] utilizes artificial neural systems to anticipate the wind speeds distribution crosswise over Nigeria and contrasted the anticipated wind speeds and estimations data from 28 stations that range somewhere in the range of 1983 and 2003. This study predicted monthly average wind speed ranging from least of 0.8m/s for Ondo (in south region) to maximum value of about 13.1m/s for Kano (in north region) with both values occurred in December. The overall annual wind speed of 4.7m/s was predicted for Nigeria. The measured data presented in this study indicated that maximum average annual wind speed of 9.47m/s was recorded in Jos closely followed by 9.39m/s in Kano. Both the monthly measured and predicted mean wind speeds detailed by this researcher are commonly higher than past investigations. On an across the nation scale, use of wind energy for power production can only be accomplished and be viable in restricted areas such as Gusau, Jos, Kano and Sokoto. These areas have average annual wind speeds of more than 6m/s according to the author.

4. DISCUSSION

According to [5, 20-25], the average annual wind speeds of at least 4-4.5m/s are required for a small wind generator to produce enough electricity. It is seen that from the reported data of the reviewed papers, average annual wind speed ranged from 4.3-9.39m/s and Weibull scale (c, m/s) and shape (k) parameters ranged from 7.34-11.24, 4.45-10.68 respectively. In addition to that the average annual power densities ranged from 147.65 to 956.2W/m^2 and capacity factors for the reviewed papers for some model of wind turbines felt between the ranges of 15-78.99% respectively. The data of the wind speed shows almost the same trend with a pronounced peak in each case, this shows good indication for electrical energy production in the study area. For the wind power densities at some selected hub heights the location considered appeared to have potential for wind energy harvests. Another way of comparing the performance characteristics of a wind turbine is by considering the capacity factor of the Wind Energy generators in a given site. Based on the reported data by two authors the capacity factors of some model turbines, the location shows potentiality of wind energy electricity.

From the recent reviewed hereof, some of the researchers analyzed just a year wind speed data which is not enough to estimate the wind energy potential of the targeted site as suggested by many literatures in the field of wind energy, analyzing the data of at least 3-5 years or more can play an important role in providing the required information. In addition to that, some of the authors did not calculate the capacity factors of the wind generators in their study which made the analysis inconclusive. For assessment of wind energy to be comprehensive one need to take full consideration of all wind energy potential elements. From the study, it is obvious that most of the research works in Kano used Weibull and Rayleigh distribution for modeling of wind potential characteristics.

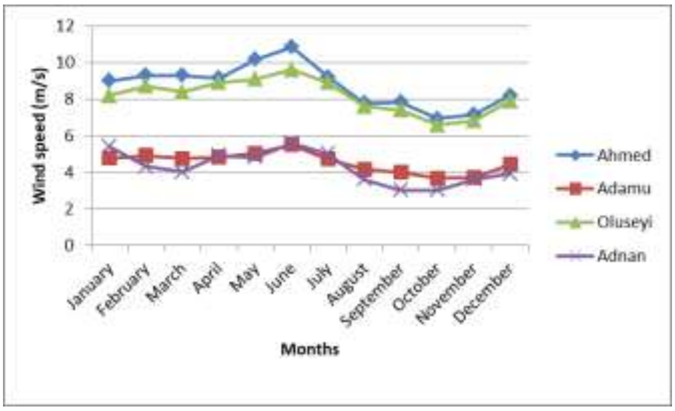

Chart 4: Average monthly wind speeds(m/s) for some reviewed data

5. CONCLUSIONS AND RECOMMENDATIONS

The energy content in a wind at a particular site is critically influenced by the wind speed, since the power output varies with cubic values of wind speed. In planning wind energy conversion system, wind speed and energy potential analysis are the first major steps to be performed. The power output from wind turbine is controlled by the design of wind turbine such as cut in, cut out and rated wind speeds to deliver useful power. For the most part, the cut in speed for the wind turbine is in the scope of 2.5-3.5 m/s and the cut-out speed ranges from 20 to 25 m/s. The evaluated power yield is generated from wind turbines when the wind speed is above the rated wind speed of the machine around 12 m/s. Likewise, the availability and consistency of this wind speed are fundamental so as to decide the economic viability of the wind energy.

For wind energy resources to be exploited in Kano for electricity generation, lots of fundamental works must be done in the areas of education and training. Also, it is important to completely conduct a detailed estimation of the wind conditions (temperature, speed, and direction) on the focused area and the nature of the topology of the site should be considered. Conclusively, based on the reviewed papers Kano has the potential of using wind energy as a source of generating electricity.

The following are recommended:

1. The studies literature should be enlarge to cover more research papers.
2. The study should be carrying out time to time in order to update the existing ones.

REFERENCES

1. Ejieji C. I (2006). An Evaluation wind energy potentials in Ilorin, Kwara state of Nigeria, ife Journal of Technology Vol. 15, pp. 27-35

2. Akpinar E. K and Akpinar S. (2004). Statistical analysis of wind energy potential on the basis of Weibull and Raleigh distribution for Agin – Elezig pp. 557-565.

3. Mabel M. C and Fernandez E. (2009). Energy Yield from wind farm using Artificial Neural Network. IEEE Transaction on Energy Conversions, 24(2): 459-464.

4. Johnson G. L. (1994). Wind Energy Systems Electronic Edition published by prentice Hall.

5. Clarke S (2003): Electricity Generation Using Small Wind Turbines at your home or farm, FACTSHEET.

6. Lawan S M, Abidin W. A. W. Z, Chai W. Y, Baharun A, and Masri T (2013). Recent progress and Development of Wind Energy Potential in Malaysia: A Review. World Applied Sciences Journal 28(9): 1222-1232.

7. Weibull W. (1951). A statistical distribution functions of wide applicability, J. Appl. Mech-Trans 18(3) ASME, 293-297.

8. Ahmed A, Bello A. A, Habou D (2013). An investigation of wind characteristics and techno-economic evaluation of wind energy in Nigeria. International Journal of Energy and Power Engineering. Vol. 2, No. 5, pp. 184-190

9. Adamu A. A and Abdullahi I (2011a): Wind energy potential of Northwestern Nigeria. Journal of Engineering and Technology Vol. 6 No 1&2 pp. 93-101.

10. Adamu A. A and Abdullahi I (2011b): Wind-electricity generation potential for selected Regions in Northwestern Nigeria. Journal of Engineering and Technology Vol. 6 No. 1&2 pp. 102-111.

11. Oluseyi Ajayi O, Richard Fagbanle O, James Katende, Samson Aasa A and Joshua Okeniyi O (2013). Wind Profile Characteristics and Turbine Performance Analysis in Kano, Northwestern Nigeria. Journal of Energy and Environmental Engineering 4:27.

12. Joseph Aidan (2014). An assessment of Wind Availability for Turbine power generation in Kano, Nigeria. Journal of Applied Physics Vol.6, Issue 5, Version 2 pp. 30-36.

13. Aliyu Maje Adnan, Faralu Muhammad Sani and Mahdi Makoyo (2014). Prospects of Establishing Small Wind Turbine Systems in Kano State, Nigeria. International Journal of Engineering Research and Applications. Vol. 4 (Version 1) pp. 01-6.

14. Fadare D. A (2010). The Application of artificial neural networks to mapping of wind speed profile for Energy application in Nigeria. Applied Energy. 87: 934-942.

15. Adaramola M. S and Oyewola O M (2011). Wind Speed distribution and Characteristics in Nigeria. Journalof Engineering and Applied Sciences. Vol. 6, No. 2, 82-86.

16. Ahmed S. (2011). Wind Energy Theory and practice. PHI learning private limited New Delhi.

17. Ajayi O. O (2009a): Assessment of Utilization of Wind Energy Resources in Nigeria. Ener. Pol. 37(2), 720-723.

18. Ajayi O. O (2010b): The potential for wind energy in Nigeria. Wind Eng. 34(3), 303-312.

19. Kothari D P, Singal K C, and Rakesh Ranjan (2012): Renewable Energy Sources and Emerging Technologies. 2nd Edition. PHI Learning Private Limited New Delhi-110001.

20. Ohunikan O. S (2011): Wind Resources Evaluation in Six selected high altitude locations in Nigeria. Renewable Energy 36, 3273-3281.

21. Saidur R, Islam M. R, Rahim N A and Solangi K. H (2010). A Review on Global Wind Energy Policy. Renewable and Sustainable Energy Reviews, 14: 1744-1762.

22. Adekoya, L.O.and A.A Adewale (1992): Wind energy potential of Nigeria. Journal of Renewable energy. 2(1): 35-39.

23. Anyawu, E.E. and C.J Iwuagwu (1995): Wind characteristics and energy Potentials for eweri, Nigerian. Renwable energy, 6(2): 125-128.

24. Enaburekan, J.S. (2007): Wind energy Technology. Unpublished Lecture note, Bayero University Kano, Nigeria.

25. Ojosu. J.O. and R.I Salawu (1990): wind energy development in Nigeria. Nigeria journal of solar energy, vol 9: 29-32

26. J. O. Okeniyi, O. S. Ohunakin and E. T. Okeniyi. 2015. Assessments of Wind-Energy Potential in Selected Sites from Three Geopolitical Zones in Nigeria: Implications for Renewable/Sustainable Rural Electrification. The Scientific World Journal. Vol.2015.