FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 6 No. 1, March, 2022, pp 222 - 231
DOI: https://doi.org/10.33003/fjs-2022-0601-828

ASSESSMENT OF WIND ENERGY POTENTIAL FOR ACCRA, GHANA USING TWO PARAMETER WEIBULL DISTRIBUTION FUNCTION

***[1]Akpootu, D. O and [2]Fagbemi, S. A**

[1]Department of Physics, Usmanu Danfodiyo University, Sokoto, Nigeria
[2]Department of Physics, Federal University Dutsin-Ma, Katsina, Nigeria

*Corresponding authors' email: **davidson.odafe@udusok.edu.ng; profdon03@yahoo.com**

ABSTRACT

This study investigates the predictive ability of two-parameter Weibull distribution function for Accra, Ghana using fifteen years (2002 – 2016) meteorological parameter of monthly mean wind speed data. The monthly and annual averaged wind speed was estimated to be $4.3102\ ms^{-1}$. The annual mean values of the maximum energy – carrying wind speed and most probable wind speed were found to be $4.5949\ ms^{-1}$ and $4.4362\ ms^{-1}$ respectively. The two parameters of the Weibull statistics found in this study for Accra were within the range $6.2680 \le k \le 14.7761$ for the shape parameters and $3.7291\ ms^{-1} \le c \le 5.4273\ ms^{-1}$ for the scale parameters. The results of the wind power density indicated that the location has a good prospect for wind power generation with the highest value of $157.5603\ Wm^{-2}$ found in September, 2006. The linear relationship between the monthly mean wind power density and mean wind speed shows that a perfect correlation with coefficient of correlation of 99.3 % exists between them. The results obtained from this study revealed that the Weibull function was found appropriate for analyzing measured wind speed data and in predicting the wind power density for the region under investigation. Therefore, Accra has an excellent prospect for wind power generation.

Keywords: wind power generation, weibull distribution function, coefficient of correlation, wind power density, Accra

INTRODUCTION

Energy has been defined as the ability to do work, a force multiplier that enhances man's ability to convert raw materials into useful products, providing varieties of useful services (Ridao *et al*., 2007). Energy demand increases with increasing numbers of human beings. Because of their benefits, Governments and societies become interested to renewable energies. Wind energy is now one of the most cost-effective and never ending natural resource; therefore wind energy becomes one of the most efficient sources of renewable energy (Noviadi and Adnan, 2018). The knowledge of wind speed can be used to obtain information about the energy potential. One of the techniques for identification of wind energy potential for a specified region is the probability distribution of wind speed (Noviadi and Adnan, 2018). The concern over the production of adequate and sustainable electricity to drive economic developments is a global issue. Although the conventional sources of fossil fuel burning have been able to produce surplus amount of energy, its finite nature is a concern for the future. Employing environment friendly and non-toxic sources for energy production has gained wide acceptance across the globe. This is because these sources which include wind, solar and hydro are non-depletable and so containing sustained potentials for abundant energy generation (Nze-Esiaga and Okogbue, 2014).

Nowadays, West Africa faces the challenge of generating more electricity to meet existing and future demand in a sustainable way (Brew-Hammond and Kemausuor 2009; Deichmann *et al*., 2011). Wind is an inexhaustible resource whose energy utilization has been increasing around the world at an accelerating pace while the development of new wind projects continues to be hampered by the lack of reliable and accurate wind resource data in many parts of the world, especially in the developing countries (Ayenagbo *et al*., 2011; Mentis *et al*., 2015). Commonly used functions for fitting the measured wind speed probability distribution in a given location over a certain period of time, typically monthly or yearly, are the Weibull, the Rayleigh and Lognormal. Amongst the most common distribution models, the Weibull function is accepted as the best model. Weibull distribution, a particular case of the generalized gamma distribution law, is characterized by the shape parameter K and the scale parameter C. The two Weibull parameters help to determine the wind characteristics (Guenoukpati *et al*., 2020). Several studies have been carried out to investigate the wind power potential for different locations across the globe using wind speed data. Acakpovi et al. (2017) proposes a database of reliable wind velocities across the whole Ghana divided into 24 locations, based on data collected for the year 2013, the proposed data were obtained through extrapolation of RETScreen data on wind velocity in Ghana, originally taken at a height of 10 m to a height of 60 m, adequate for generation using Weibull distribution function. According to them, the model led to the determination of the shape factor k and the scale factor c for all the 24 locations which subsequently led to the extrapolated wind velocity. The lowest and highest wind speeds were recorded, respectively, as 3.77 and 8.24 m/s for Wenchi and Wa locations in Ghana. In another study, Olomiyesan (2018) studied the predictive ability of two-parameter Weibull distribution function in analyzing wind speed data in two selected sites with different mean wind speeds in the North-Western region of Nigeria. Twenty-two years wind speed data spanning from 1984 to 2005 was used in his analysis. The data were obtained from the Nigerian

Meteorological Agency (NIMET) in Lagos. The results of the analysis revealed that Weibull function is suitable for analyzing measured wind speed data and in predicting the wind-power density in both locations and that Weibull function is not discriminative between locations with high and low mean wind speeds in analyzing wind data. The annual mean wind speeds for the two sites (Sokoto and Yelwa) are 7.99 ms^{-1} and 2.59 ms^{-1} respectively, while the annual values of the most probable wind speed and the maximum, energy-carrying wind speeds are respectively: 3.52 and 4.34 ms^{-1} for Yelwa and 8.33 and 9.02 ms^{-1} for Sokoto. The estimated annual wind power densities for Yelwa and Sokoto are respectively 36.91 and 359.96 Wm^{-2}. According to him, Sokoto has a better prospect for wind power generation. Also, Guenoukpati et al. (2020) evaluated the effectiveness of seven numerical methods to determine the shape (K) and scale (C) parameters of Weibull distribution function for the purpose of calculating the wind speed characteristics and wind power density. The selected methods are graphical method (GPM), empirical method of Justus (EMJ), empirical method of Lysen (EML), energy pattern factor method (EPFM), maximum likelihood method (MLM) moment method (MOM) and the proposed. Hybrid method (HM) derived from EPFM and EMJ. The purpose of their study was to identify the most appropriate method for computing the mean wind speed, wind speed standard deviation and wind power density for different costal locations in West Africa. Three costal sites (Lomé, Accra and Cotonou) are selected. The input data was collected, from January 2004 to December 2015 for Lomé site, from January 2009 to December 2015 for Accra site and from January 2009 to December 2012 for Cotonou. The results indicated that the precision of the computed mean wind speed, wind speed standard deviation and wind power density values change when different parameters estimation methods are used. Five of them which are EMJ, EML, EPF, MOM, ML, and HM method present very good accuracy while GPM shows weak ability for all three sites. More recently, Akpootu et al. (2022) used 31 years (1980–2010) monthly wind speed data to investigate the predictive ability of two-parameter Weibull distribution function for Warri and Port Harcourt located in the Coastal region of Nigeria. The result in their study revealed that the Weibull function was found suitable for analyzing measured wind speed data and in predicting the wind power density in the locations under study. The monthly mean wind speed for Warri and Port Harcourt are 3.3433 and 3.3062 ms^{-1}, respectively. The annual values of the most probable wind speed and maximum energy-carrying wind speed are 3.3483 and 4.2307 ms^{-1}, respectively, for Warri and 3.4342 and 3.8783 ms^{-1}, respectively, for Port Harcourt. The two parameters of the Weibull statistics were found to lie between $2.5524 \leq k \leq 5.1206$ for Warri, $3.6436 \leq k \leq 6.1214$ for Port Harcourt and $3.0028 \leq c \leq 4.3221$ for Warri, $2.7228 \leq c \leq 4.1074$ for Port Harcourt. The results of the relationship between the monthly mean wind power density and mean wind speed revealed a perfect correlation for Warri and Port Harcourt with coefficient of correlation of 99.6% and 99.4% respectively. The estimated monthly mean wind power density for Warri and Port Harcourt are 23.8173 and 23.2159 Wm^{-2}, respectively which according to them indicated that Warri has slightly higher better prospect for wind power generation as compared to Port Harcourt.

There is an apparent assumption on the existence of strong wind velocities in Ghana that can be exploited for wind power production (Acakpovi *et al*., 2017). However, the availability of the wind resource that is necessary for exploitation is still a big limitation. In Ghana, the Energy Commission is in charge of collecting wind data, but so far their coverage is limited to some few regions which are relatively insignificant compared to a nationwide data. The areas covered with wind data in Ghana by the Energy Commission are very limited (Seth and Modjinou, 2012). This study employed more quantity of wind speed data for Accra as compared to those found in the literature and distinguished distinctively the mean power density based on large/scale scale electric wind application for each month and year for the period under study.

The aim of this study is to investigate the wind power potential for Accra, Ghana by employing two parameter Weibull distribution functions using monthly wind speed meteorological data during the period of fifteen years (2002 – 2016).

STUDY AREA

In Akpootu et al. (2021), the climate of Ghana is tropical with two main seasons: the wet and the dry seasons. North Ghana experiences its rainy season from April to mid-October while South Ghana experiences its rainy season from March to mid-November. The tropical climate of Ghana is relatively mild for its latitude. The harmattan, a dry desert wind, blows in north-east Ghana from December to March, lowering the humidity and causing hotter days and cooler nights in northern part of Ghana. Average daily temperatures range from 30°C (86°F) during the day to 24°C (75°F) at night with a relative humidity between 77 % and 85 %. In the southern part of Ghana, there is a bi-modal rainy season: April through June and September through November. Squalls occur in the northern part of Ghana during March and April, followed by occasional rain until August and September, when the rainfall reaches its peak. Rainfall ranges from 78 to 216 cm (31 to 85 inches) a year.

In Accra, the wet season is mostly cloudy, the dry season is partly cloudy, and it is hot and oppressive year round. Over the course of the year, the temperature typically varies from 74°*F* to 91°*F* and is rarely below 73°*F* or above 93°*F*. The *hot season* lasts for *5.8 months*, from *November* 17 to May 11, with an average daily high temperature above 89°*F*. The hottest day of the year is February 25, with an average high of 91°*F* and low of 79°*F*. The *cool season* lasts for 2.2 months, from July 3 to September 9, with an average daily high temperature below 83°*F*. The coldest day of the year is August 7, with an average low of 74°*F* and high of 81°*F*. The average percentage of the sky covered by clouds experienced significant seasonal variation over the year. The clearer part of the year in Accra begins around June 27 and lasts for 7.5 months, ending around February 11. On December 25, the clearest day of the year, the sky is clear, mostly clear, or partly cloudy 59% of the time, and overcast or mostly cloudy 41% of the time (Wikipedia, 2021). The study area under investigation is Accra (Latitude 5.6 °N, Longitude -0.16 °W and altitude 68 m above sea level) with weather station number 654720 (DGAA) as shown in figure 1.

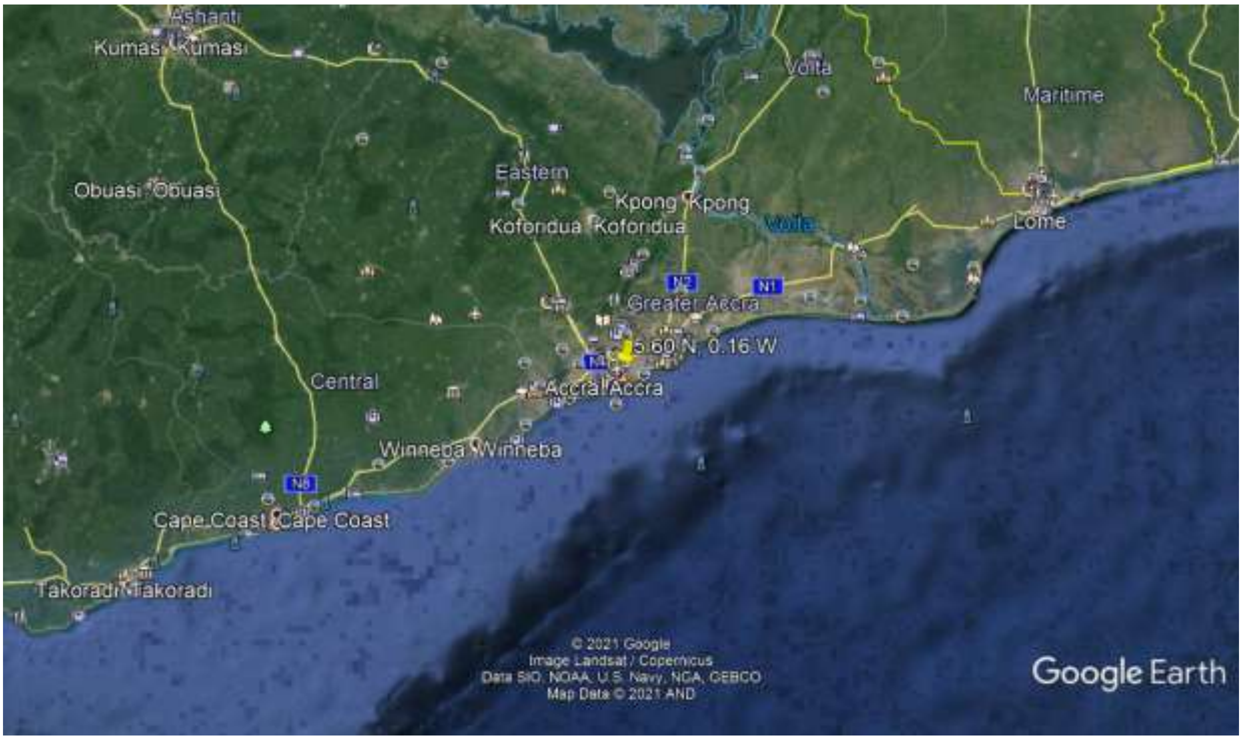

Figure 1: Google map showing the location under investigation

METHODOLOGY

The measured daily climatic data of wind speed used in this study were obtained online from the Tutiempo Network, S.L (en.tutiempo.net/climate/ws-654720.html). The daily data were averaged into monthly data. Also, the monthly data were averaged into yearly data. The study area under investigation is Accra (Latitude 5.6 ° N, Longitude -0.16 ° W and altitude 68 m above sea level) with weather station number 654720 (DGAA). To avoid possible misleading indications related to yearly variation in weather condition, the period under investigation is fifteen years (2002 – 2016) so as to obtain a good climatological average. The quality assurance of the meteorological measurements as suggested in Akpootu et al. (2017) was determined by checking the overall consistency of the daily, monthly and yearly average of the climatic parameters used in the study area.

Since wind is a stochastic valued event, it is better to describe the variation of wind speeds by a statistical function. The probability distribution function (pdf) of the two-parameter Weibull distribution (Equation (1)) is often used in characterizing the distribution of wind speeds measured frequently over a period of a month, a year, or several years (Ajavon *et al*., 2015; Safari 2011). The analysis of wind distribution for Accra, Ghana was carried out using Weibull distribution function. The Weibull probability density function, $f_w(V)$ and the corresponding cumulative distribution function, $F_w(V)$ are given as (Dikko and Yahaya, 2012).

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

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

where

v is the wind speed in ms^{-1}, c is the scale factor/parameter in ms^{-1} and k is the shape factor/parameter and is dimensionless.

Guenoukpati et al. (2020) describes six existing and one proposed numerical methods for evaluating the values of the Weibull parameters k and c from measured wind speed data. These methods are the Graphical Method (GPM), Empirical Method of Justus (EMJ), Empirical Method of Lysen (EML), Energy Pattern Factor Method (EPFM), Maximum Likelihood Method (MLM), Moment Method (MOM) and the proposed (Hybrid EPFM-EMJ). The values of the Weibull parameters k and c in this study were calculated using the Empirical method or Standard Deviation Method (SDM). This method has relatively simple expressions when compared with other methods stated above and is useful where only the mean wind speed and standard deviation are available (Justus *et al*., 1978; Jowder, 2009; Oyedepo *et al*., 2012). The standard deviation method has been expressed in equations (3) and (4) as given by (Justus *et al*., 1978):

$$k = \left(\frac{\sigma}{v_m}\right)^{-1.086} \qquad (3)$$

$$c = \frac{v_m}{\Gamma\left(1+\frac{1}{k}\right)} \qquad (4)$$

Alternatively, c can be evaluated using the equation given by Ahmed (2011).

$$c = v_m \left[\frac{k^{2.6674}}{0.184 + (0.816\, k^{2.73859})}\right] \tag{5}$$

The standard deviation, σ was obtained using

$$\sigma = \left[\frac{1}{N-1}\sum_{i=1}^{N}(v_i - v_m)^2\right]^{1/2} \tag{6}$$

where

v_m is the mean wind speed in ms^{-1}, v_i is the observed wind speed in ms^{-1}, N is the number of months in the period of time considered and $\Gamma(x)$ is the gamma function, which is defined as:

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

Furthermore, some important parameters for wind resources analysis that can be expressed in terms of Weibull shape and scale factors, k and c are the maximum energy carrying-wind speed and the most probable wind speed. The maximum energy carrying-wind speed, VE_{max} and the most frequent wind speed, V_{mp} can be expressed as given in equations (7) and (8) respectively (Arslan, 2010)

$$VE_{max} = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \tag{7}$$

$$V_{mp} = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \tag{8}$$

The wind power density is an important indicator to determine the potential of wind resources and to describe the amount of wind energy at various wind speed values in a particular location (Guenoukpati *et al*., 2020). The knowledge of wind power density is also useful to evaluate the performance of wind turbines and nominate the optimum wind turbines. Wind power density represents the amount of energy available on the site which can be converted to electricity by using wind turbines (Guenoukpati *et al*., 2020). Indeed, the mean kinetic energy, available on a site per unit time and per unit area is expressed by Equations (9 and 10). The wind power density, ρ_{wd} in Wm^{-2} can be expressed either in terms of the wind speed or in terms of the Weibull shape and scale parameters, k and c using the correlations given by Celik (2003)

$$\rho_{wd} = \frac{1}{2}\rho v^3 \tag{9}$$

$$\rho_{wd} = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \tag{10}$$

where k, c and v are as previously defined. ρ is the air density at the site, which can be expressed in the form:

$$\rho = \rho_0 - 1.194 \times 10^{-4} \times H_m \tag{11}$$

where H_m is the site elevation in meters and ρ_0 is the air density value at sea level usually taken as $1.225\ Kg\ m^{-3}$

RESULTS AND DISCUSSION

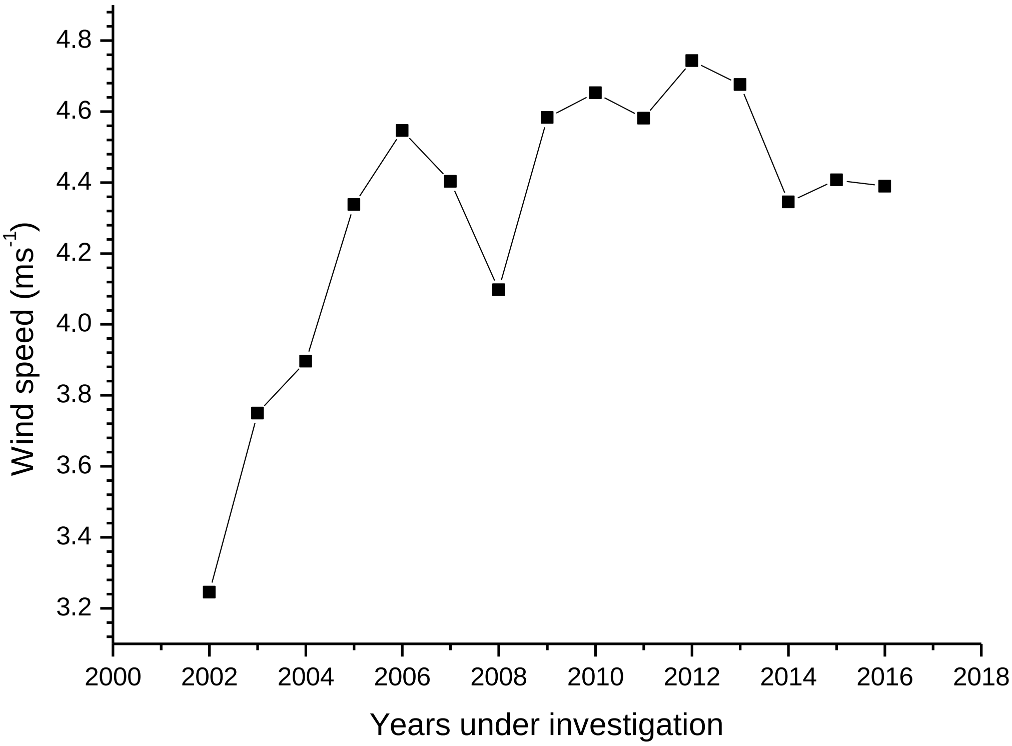

Figure 2(a). Annual mean wind speeds over Accra (2002 – 2016)

Figure 2(a) shows the annual variation of wind speed over Accra for the period under study. It is obvious from the figure that the wind speed varies from year to year. The highest and lowest values of wind speed for the location were found to be $4.7431\ ms^{-1}$ and $3.2454\ ms^{-1}$ in the year 2012 and 2002 respectively. The percentage of the annual wind energy above the $3.00\ ms^{-1}$ cut-in wind speed which contributes to the generation of electricity from wind in most new wind turbine designs for Accra is 100 %. The implication of this is that wind turbines installed in these locations will work for most of the time

.

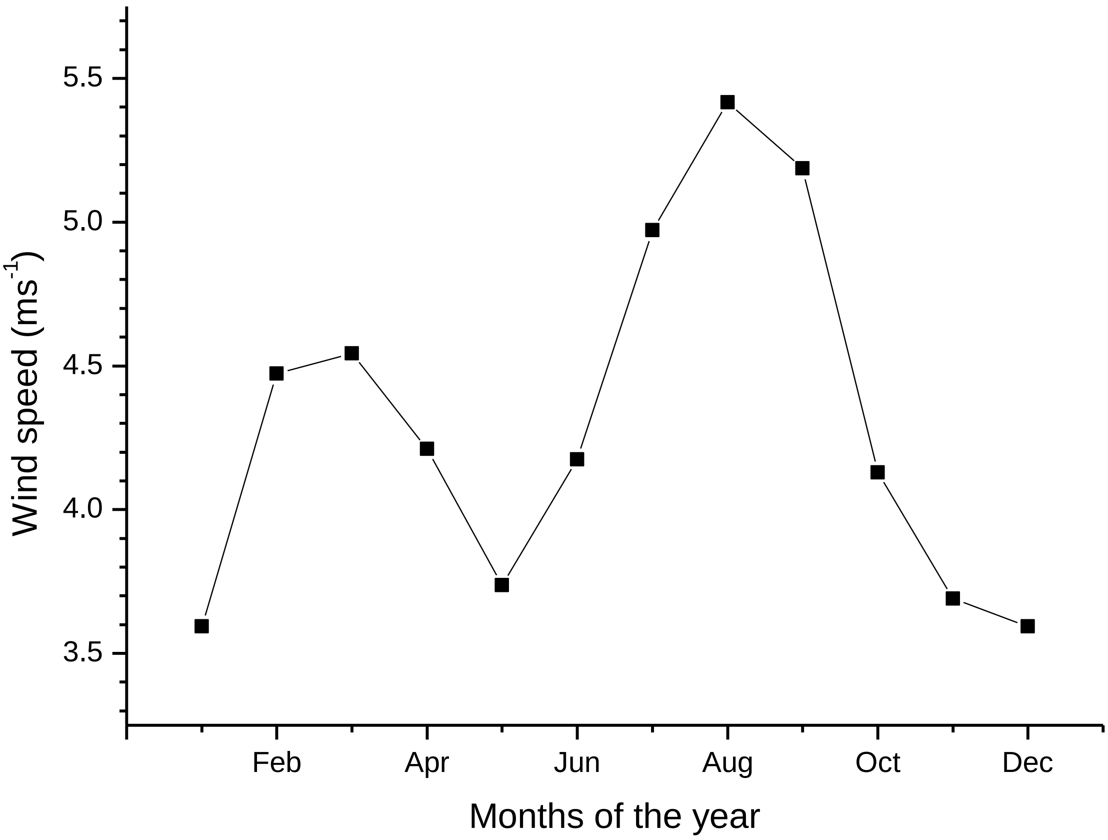

Figure 2(b). Monthly mean wind speeds over Accra

Figure 2(b) shows the monthly variation of wind speed for the location under investigation. The figure depicts that the value of wind speed in each month for Accra varies significantly. The highest monthly mean value of wind speed was found to be $5.4167\ ms^{-1}$ in the month of August and the lowest monthly mean value was found to be $3.5944\ ms^{-1}$ in the months of January and December respectively. The result as revealed from the figure indicated that high values of wind speed were recorded during the rainy season than in the dry season. The monthly average daily wind speed for the period under study was evaluated to be $4.3102\ ms^{-1}$ which is in close agreement with those reported by Guenoukpati et al. (2020) where they obtained mean wind speed value of $4.1603\ ms^{-1}$ using record length of seven years (2009 – 2015) for Accra while Acakpovi et al. (2017) obtained mean wind speed value of $5.1600\ ms^{-1}$ using one year data (2013) for Accra.

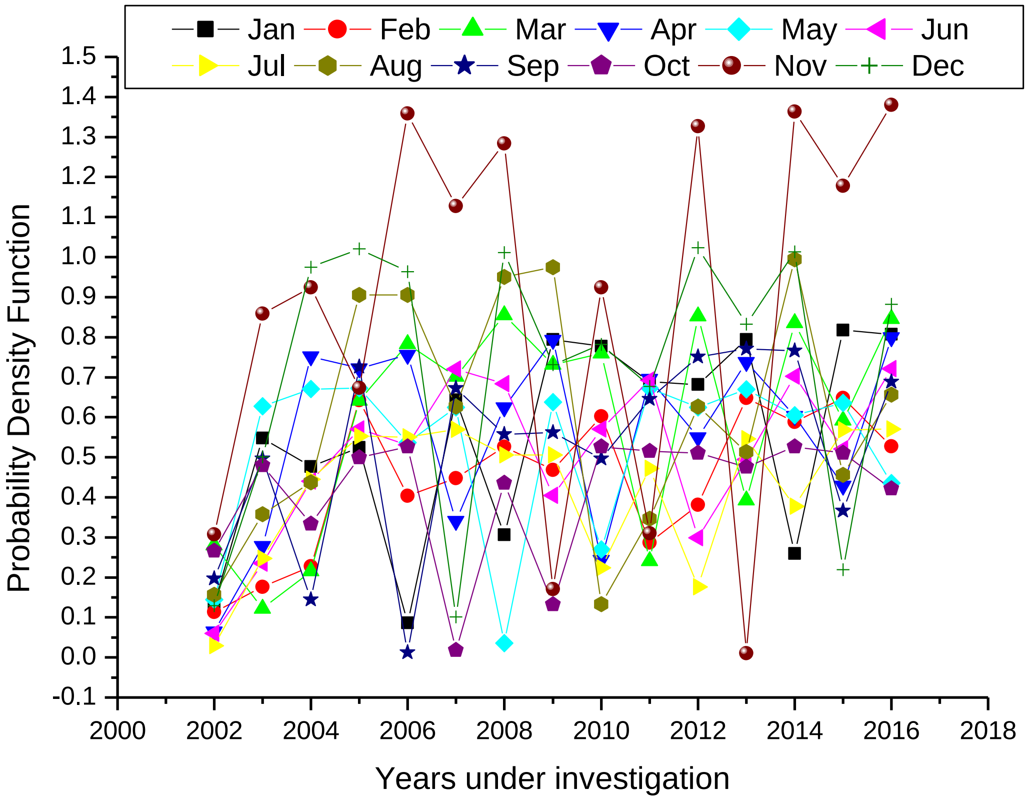

Figure 3(a). Probability density function from the Weibull analysis for Accra

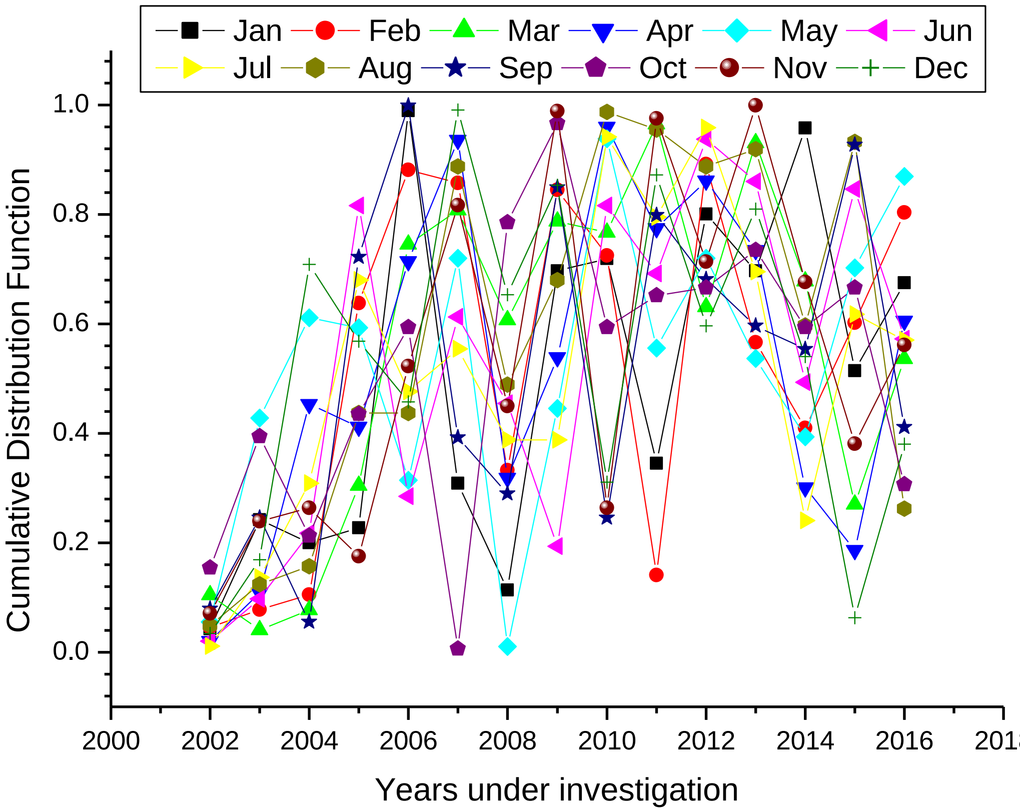

Figure 3(b). Cumulative distribution function from the Weibull analysis for Accra

Figure 3(a) and 3(b) shows the Probability Density Function (PDF) and Cumulative Distribution Function (CDF) for Accra during the studied period. The figure revealed that the wind speed profiles for the study periods follow similar cumulative distribution patterns. The differences in the shapes of the PDF and CDF from the figures are as a result of the varying values of the Weibull parameters (k and c) and this in line with the study reported by Akpootu et al. (2022).

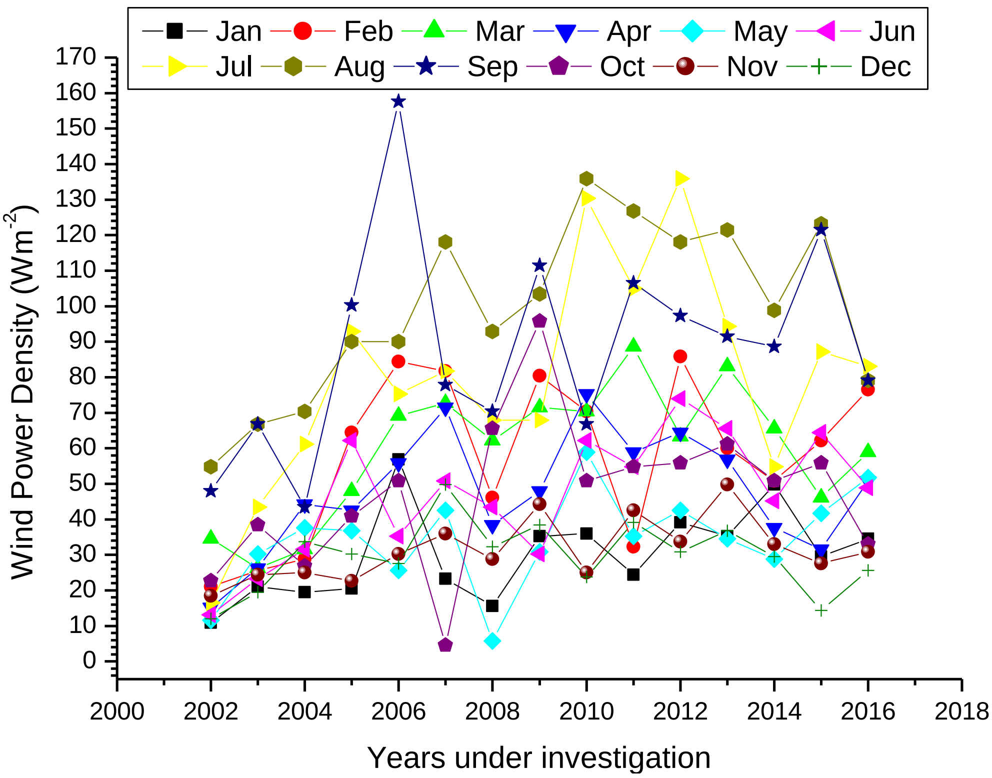

Figure 3(c). Annual wind power density for Accra

Figure 3(c) shows the annual wind power density for the location and period under investigation. The highest annual wind power potential has its peak value of 157.5603 Wm^{-2} in September, 2006 and its lowest value of 4.5002 Wm^{-2} in October, 2007. The significant monthly change in wind power density as reported by Keyhani et al. (2010) underscores the importance of distinguishing the various months and periods of the year under study when a wind power project is assessed or designed to produce maximum power (Nze-Esiaga and Okogbue, 2014). Celik (2003) and Keyhani et al. (2010) have reported that mean power density of less than 100 Wm^{-2} are not suitable for large-scale electric wind application. But, small-scale wind turbines could be a good option in order to supply power for lightings, electric fans, chargers and air conditioning units for small houses (Mostafaeipour *et al.*, 2011). In view of this, the results in this study revealed that July 2010, 2011, 2012; August 2007, 2009, 2010, 2011, 2012, 2013, 2015; September 2005, 2006, 2009, 2011, 2015 has mean power density values greater than 100 Wm^{-2} and therefore these periods are suitable for large-scale electric wind application while the remaining periods under study, small-scale wind turbines could be a good option. Generally, the location has a good prospect for wind power generation.

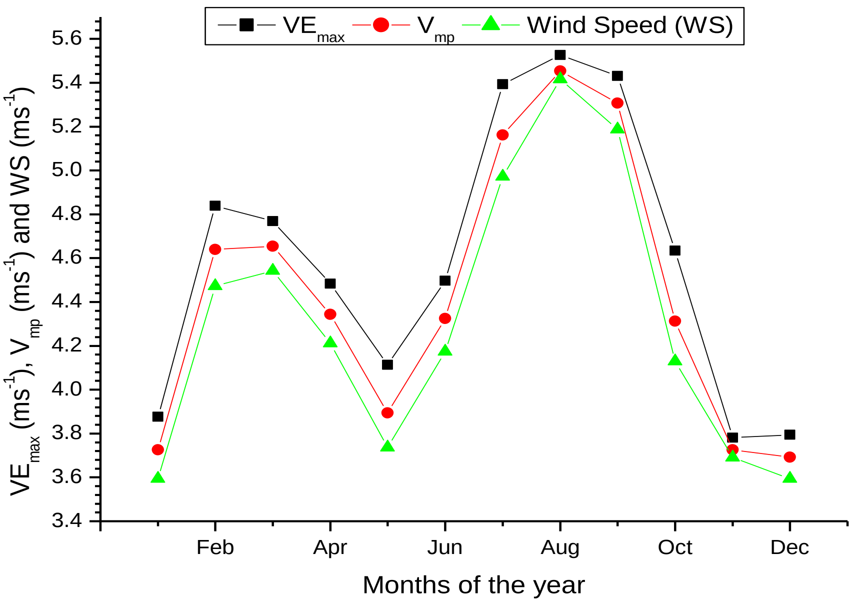

Figure 4(a). Maximum energy carrying wind speed, most probable wind speed and wind speed for Accra

Figure 4(a) shows the monthly variation of maximum energy carrying wind speed, most probable wind speed and wind speed for Accra. The findings in this study revealed that the values of the maximum energy carrying wind speed is higher than the most probable wind speed and wind speed throughout the months for the period under study. This is in agreement with the study reported by Akpootu et al. (2022). However, in this study the maximum energy carrying wind speed has the highest values, and this was followed by the most probable wind speed and then the wind speed; this occurred throughout the months for the studied period. The values of the monthly maximum energy carrying - wind speed ranged between 3.7810 ms^{-1} and 5.4314 ms^{-1}, the monthly most probable wind speed ranged between 3.6925 ms^{-1} and 5.4533 ms^{-1} while the monthly wind speed ranged between 3.5944 ms^{-1} and 5.4167 ms^{-1}. Nze-Esiaga and Okogbue, 2014 has reported that the most probable wind speed corresponds to the peak of the probability density function, while the wind speed carrying maximum energy can be used to estimate the wind turbine design or rated wind speed

.

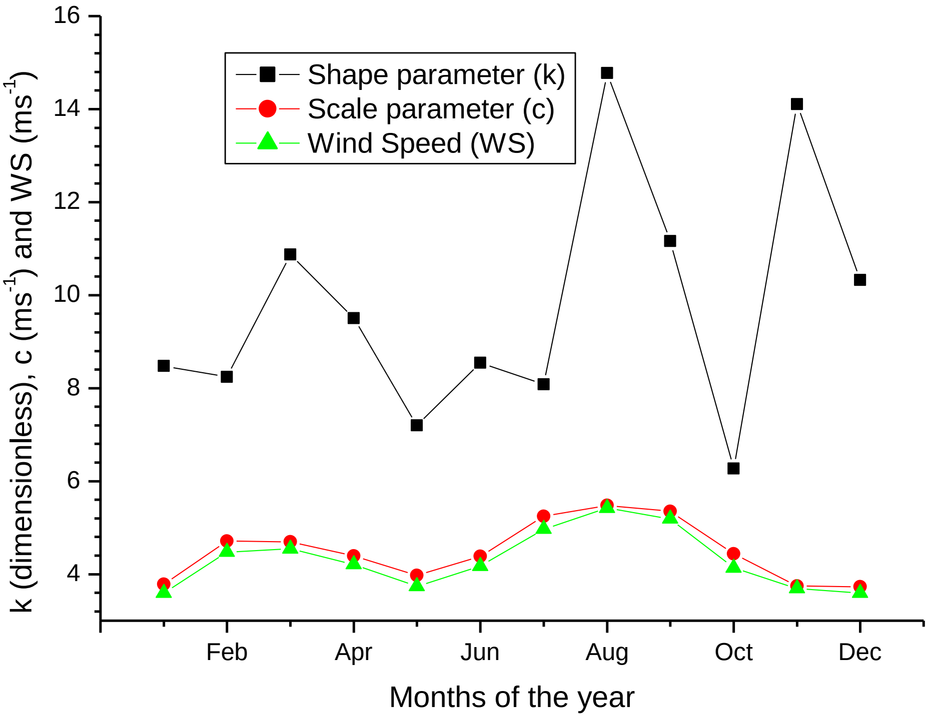

Figure 4(b). Monthly weibull parameters (k and c) and wind speed for Accra

Figure 4(b) shows the monthly variation of the Weibull parameters (k and c) and mean wind speed for Accra during the studied period. It is clear from the figure that the shape parameters, k shows a remarkable high values as compared to the scale parameter, c and wind speed throughout the months of the investigation period. The values of the scale parameters, c are higher than that of the wind speed; with similar pattern of variation. The range of values for the Weibull parameters (k and c) from the analysis of this study for Accra revealed $6.2680 \leq k \leq 14.7761$ and $3.7291\ ms^{-1} \leq c \leq 5.4273\ ms^{-1}$. The high values of the Weibull parameters ($k \geq 2$ and $c \geq 2$) implies that the data spread in a perfectly normal distribution (Carta et al., 2009; Eze-Esiaga and Okogbue, 2014) and that the data spread exhibits good uniformity with relatively small scatter (Lipson and Sheth, 1973). The scale parameter, c also show how windy the location under investigation is, while the shape parameter, k show how peaked the wind distribution is (Keyhani *et al*., 2010). Therefore, if the wind speeds tends to spike steeply at a certain value, the distribution would have high shape parameter, k value (Eze-Esiaga and Okogbue, 2014).

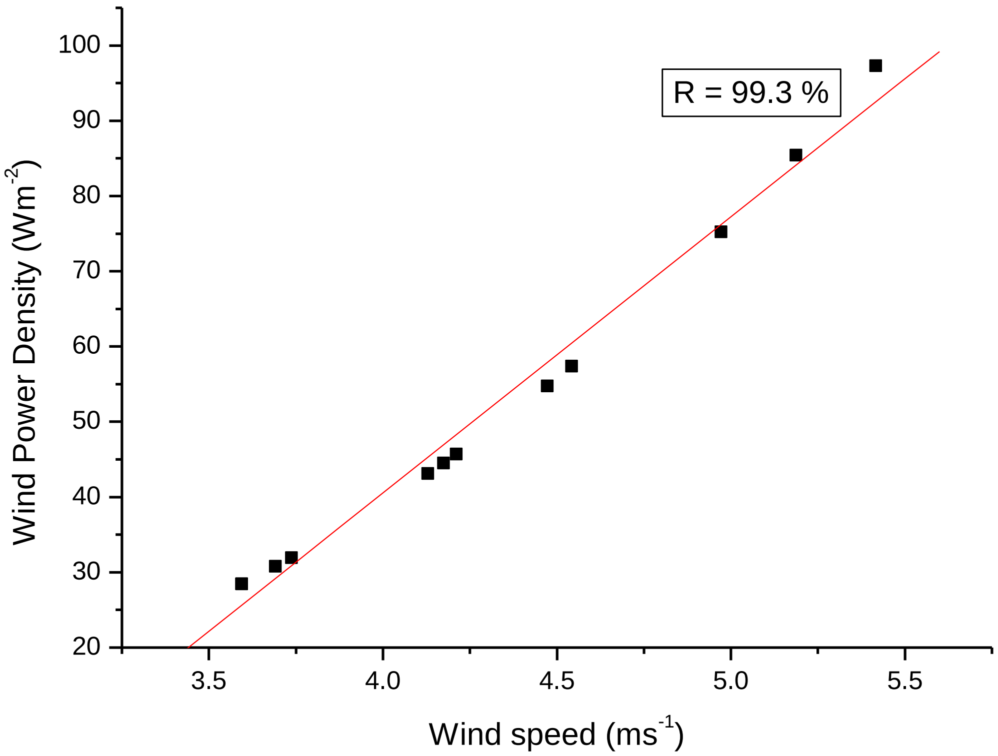

Figure 5. Relationship between mean wind speed and wind power density for Accra

Figure 5 depicts how the monthly mean wind speed is related to the monthly mean wind power density. The result indicated that a perfect relationship with coefficient of correlation of 99.3 % exists between the two variables.

CONCLUSION

Fifteen years (2002 – 2016) meteorological data of monthly mean wind speed obtained from Tutiempo network has been used to investigate the wind power potential for Accra, Ghana using two parameters Weibull distribution function. The monthly mean wind speed values during the period under investigation ranged between 3.5944 ms^{-1} and 5.4167 ms^{-1} while the annual mean wind speed values ranged between 3.2454 ms^{-1} and 4.7431 ms^{-1}. The highest monthly mean wind speed was found to be 5.4167 ms^{-1} in the month of August while the lowest was found to be 3.5944 ms^{-1} in the month of January and December. The highest and lowest annual mean wind speed values were found to be 4.7431 ms^{-1} and 3.2454 ms^{-1} in the year 2012 and 2002 respectively. The percentage of the annual wind energy above the 3.00 ms^{-1} cut-in wind speed which contributes to the generation of electricity from wind in most new wind turbine designs is 100 % for Accra, Ghana. The high values of Weibull parameters ($k \geq 2$ and $c \geq 2$) in this study implies that the data spread in a perfectly normal distribution and further indicates that the data spread exhibits good uniformity with relatively small scatter. The result of the linear relationship between the monthly mean wind power density and mean wind speed indicated a perfect correlation with coefficient of correlation of 99.3 %. The result obtained for the wind power density which determines the efficiency of electric power generation in any location revealed that Accra has an excellent potential for electric power production during the period under investigation and is expected to be consistent at present and in the future; similar results could be obtained from region with related climatic conditions which can be investigated if measured wind speed data are available.

ACKNOWLEDGEMENT

The authors are grateful to the Tutiempo Network, S.L for providing the wind speed meteorological data used in this present study. The contribution and suggestions of the anonymous reviewers that led to improving the paper is well appreciated.

REFERENCES

Acakpovi, A., Issah, M. B., Fifatin, F. X and Michael, M. B (2017). Wind velocity extrapolation in Ghana by Weibull probability density function. Wind Engineering 1–13 DOI: 10.1177/0309524X17723205

Ahmed, S. A (2011). Investigation of Wind Characteristics and Wind Energy Potential at RasGhareb Egypt. *Renewable and Sustainable Energy Reviews*., 15, 2750 – 2755. https://doi.org/10.1016/j.rser.2011.04.003

Ajavon, A. S. A., Salami, A. A., Kodjo, M. K and Bédja, K.-S (2015). Comparative characterization study of the variability of wind energy potential by wind direction sectors for three coastal sites in Lomé, Accra and Cotonou. *Journal of Power Technologies*., 95(2), 134–142.

Akpootu, D. O and Iliyasu, M. I (2017). Estimation of Tropospheric Radio Refractivity and Its Variation with Meteorological Parameters over Ikeja, Nigeria. *Journal of Geography, Environment and Earth Science International*., 10(1): 1-12. DOI: 10.9734/JGEESI/2017/32534

Akpootu, D. O., Idris, M., Nouhou, I., Iliyasu, M. I, Aina, A. O., Abdulsalami, M. J., Ohaji, D. E and Abubakar, M. B (2021). Estimation and Investigation of the Variability of Tropospheric Radio Refractivity and Radio Field Strength over Accra, Ghana. *Journal of Atmospheric & Earth Science*., 5: 026. DOI: 10.24966/AES-8780/100026

Akpootu, D. O., Okpala, C. N., Iliyasu, M. I., Ohaji, D. E., Idris, M., Abubakar, M. B., Aina, A. O and Abdulsalami, M (2022). Investigation of wind power potential in two selected locations in the Coastal Region of Nigeria. *SCIENCE FORUM (JOURNAL OF PURE AND APPLIED SCIENCES)* 22(1), 95 – 103. http://dx.doi.org/10.5455/sf.profdon03

Arslan, O (2010). Technoeconomic analysis of electricity generation from wind energy in Kutahya Turkey. *Energy*., 35, 20-131 https://doi.org/10.1016/j.energy.2009.09.002

Ayenagbo, K., Kimatu, J. N and Rongcheng, W (2011). A model for a sustainable energy supply strategy for the social-leconomic development of Togo. *Journal of Economics and International Finance*., 3(6), 387–398.

Brew-Hammond, A and Kemausuor, F (2009). Energy for all in Africa? to be or not to be?! *Current Opinion in Environmental Sustainability*., 1(1), 83–88.

Carta, J. A., Ramırez, P and Velázquez, S (2009). A review of wind speed probability distributions used in wind energy analysis: case studies in the Canary Islands. *Renewable Sustainable Energy Reviews*., 13, 933-55. https://doi.org/10.1016/j.rser.2008.05.005

Celik, A. N. (2003). Energy output estimation for small-scale wind power generators using Weibull representative wind data. *Journal of Wind Engineering and Industrial Aerodynamics*., 91(5), 693–707.

Deichmann, U., Meisner, C., Murray, S and Wheeler, D (2011). The economics of renewable energy expansion in rural Sub- Saharan Africa. *Energy Policy*., 39(1), 215–227.

Dikko, I and Yahaya, D. B (2012). Evaluation of Wind Power Density in Gombe, Yola and Maiduguri, North Eastern Nigeria. *Journal of Research in Peace, Gender and Development*., 2(5), 115-122.

Guenoukpati, A., Salami, A.A., Kodjo, M.K., and Napo, K (2020). Estimating Weibull Parameters for Wind Energy Applications Using Seven Numerical Methods: Case studies of Three Coastal Sites in West Africa. *International Journal of Renewable Energy Development*., 9(2), 217-226 https://doi.org/10.14710/ijred.9.2.217-226

Jowder, F. A. L. (2009). Wind power analysis and site matching of wind turbine generators in Kingdom of Bahrain. *Applied Energy*., 86(4), 538–545.

Justus, C. G., Hargraves, W. R., Mikhail, A and Graber, D (1978). Methods for estimating wind speed frequency distributions. *Journal of Applied Meteorology*., 17(3), 350 – 353.

Keyhani, A., Ghasemi-Varnamkhasti, M., Khanali, M and Abbaszadeh, R (2010). An assessment of wind energy potential as a power generation source in the capital of Iran, Tehran. *Energy*., 35(1), 188–201.

Lipson, C and Sheth, N. J (1973). Statistical Design and Analysis of Engineering Experiments. McGraw Hill, New York.

Mentis, D., Hermann, S., Howells, M., Welsch, M and Siyal, S. H (2015). Assessing the technical wind energy potential in Africa a GIS-based approach. *Renewable Energy*., 83, 110–125.

Mostafaeipour, A., Sedaghat, A., Dehghan-Niri, A. A and Kalantar, V (2011). Wind energy feasibility study for city of Shahrbabak in Iran. *Renewable and Sustainable Energy Reviews*., 15(6), 2545–2556.

Noviadi, E. T and Adnan, A (2018). Identification the Potential Wind Speed for Energy in Pekanbaru Using Some Simple Mixture Distribution Modelling. *Applied Mathematical Sciences*., Vol. 12, no. 29, 1393 – 1401. https://doi.org/10.12988/ams.2018.810139

Nze-Esiaga, N and Okogbue, E. O (2014). Assessment of Wind Energy Potential as a Power Generation Source in Five Locations of South Western Nigeria. *Journal of Power and Energy Engineering*., 2, 1-13. http://dx.doi.org/10.4236/jpee.2014.25001

Olomiyesan, B. M (2018). Performance evaluation of Weibull function for wind data analysis in two selected locations in North-Western, Nigeria. *International Journal of Physical Research*., 6(1). 18 – 24.

Oyedepo, S. O., Adaramola, M. S and Paul, S. S (2012). Analysis of Wind Speed Data an Wind Energy Potential in Three Selected Locations in South-East Nigeria. *International Journal of Energy and Environmental Engineering.*, 3(7), https://doi.org/10.1186/2251-6832-3-7

Ridao, A.R., Garcia, E.H., Escobar, B.M and Toro, M.Z (2007). Solar energy in Andalusia (Spain): Present state and prospects for the future. *Renewable & Sustainable Energy reviews*., 11(1), 148–161.

Safari, B. (2011). Modeling wind speed and wind power distributions in Rwanda. *Renewable and Sustainable Energy Reviews*., 15(2), 925–935.

Seth, M and Modjinou, M (2012). Opportunities in the Ghana Renewable Energy Act 2011, Act 832.

Wikipedia (2021) Accessed online on 8th August, 2021.