

Estimation of Wind Energy Potential in Southwestern Nigeria.

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ABSTRACT

This study investigates the potential for wind energy development in Lagos, a fast growing city in southwestern Nigeria. A preliminary evaluation of Lagos's wind energy resource was undertaken to determine the suitability of the city for wind energy development. The mean wind speed, the Weibull distribution, annual energy and annual capacity factor are calculated for the site. The annual energy and annual capacity factor calculation are based on specification of wind turbine known as Vestas V42-600. This study indicates that the annual energy and capacity factor for the site were 512.11MWh and 9.7%, respectively.

(Keywords: wind energy resource, energy development, Weibull distribution, capacity factor)

INTRODUCTION

Climate change is arguably one of the greatest environmental threats the world is facing. The impacts of disruptive change leading to catastrophic events such as storms, droughts, sea level rise and floods are already being felt across the world. Emissions of CO₂ caused by human activity are generally considered the most important single source of potential future warming (Eckaus and Richard 1994). In order to have a sustainable development, the government has to take measures to utilize the renewable energy in order to satisfy part of the energy demand in Nigeria. The renewable energy resources include solar, wind, wave, geothermal and biomass. The use of wind energy can significantly reduce the combustion of fossil fuel and the consequent emission of carbon dioxide.

Wind energy is a form of solar energy caused by pressure differences across the earth's surface due to the uneven heating of the Earth by solar

radiation. The solar radiation heats different parts of the earth at different rates, most notably during the day and night because the Earth's surface is made of very different types of land and water.

Supplementing our energy base with clean and renewable sources of energy has become imperative due to the present days' energy crisis and growing environmental consciousness. Wind energy is one of renewable sources of energy that would stabilize and diversify national energy supplies. The increasing demand for energy supply coupled with limited energy resources creates an urgency to find new solutions for this energy shortage in Nigeria. Wind energy is currently underutilized for electricity production in developing countries due to technical, physical, economic and political constraints.

Knowledge of the wind speed distribution is essential for predicting the energy output of a wind energy conversion system. The distribution of wind energy at different wind speeds is commonly known as the wind power density which is calculated by multiplying the power of wind speed with the probability of each wind speed. Modeling and prediction of wind speed are essential prerequisites in the siting and sizing of wind power applications. In recent years, many efforts have been made to develop models through which the wind distribution can be estimated.

Based on wind resource data and an estimate of the real efficiency of actual wind turbines, numerous studies have been carried out in various parts of the world in order to evaluate the regionally available wind energy resource. Fadare (2009) modeled wind speed profile in Nigeria using artificial neural network consisting of 3-layered, feed-forward, back-propagation network with different configurations, designed using the Neural Toolbox for MATLAB. Amusan et al. (2007) determined the annual energy

capture potential for wind power system in Ogbomoso. Dahmouni et al. (2008) used Weibull model to evaluate wind resource in the site of Borj-Cedria in the Golf of Tunisia. The work of Mahyoub et al. (2006) showed that the Weibull distribution estimated power density better than the Rayleigh distribution. Carta et al. (2007) developed a bivariate probability model for wind power density and wind turbine energy output estimation.

MATERIALS AND METHODS

Climatic Data

In this research, a monthly average of the wind speed of Lagos from 1999 to 2009 was obtained from Nigeria Meteorological Agency, Oshodi, Lagos, Nigeria. The geographic location of the site is latitude 6°33'N and longitude 3 20°E.

Frequency Distribution of Wind Speed

The wind speed probability density distributions and their functional forms represent the major aspects in wind related literature. The probability distributions most commonly used are those of "Weibull" and "Rayleigh". The Weibull distribution has been found to fit a wide collection of recorded wind data (Ulgen and Hepbasli, 2002; Dorvol, 2002). In this paper, the Weibull method is used. The probability density function of the Weibull distribution is given by (Akpinar and Akpinar, 2005):

$$f = \left(\frac{k}{c}\right) \left(\frac{v}{c}\right)^{k-1} \times e^{-\left(\frac{v}{c}\right)^k} \quad (1)$$

where v is the wind speed, k is a shape parameter, and c is a scale parameter determined from the data. The scale parameter, c , indicates how windy a wind location is, while the shape parameter k , indicates how peaked the wind distribution is. These parameters allow the calculation of the expected monthly or annual wind power density per unit area in a given area. The corresponding cumulative probability function of the Weibull distribution is given by:

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

where $f(v)$ represents the probability for the wind speed to be lower than a certain value v .

For this present work, the scale and shape parameters were estimated using the method of maximum likelihood estimation (MLE) using Matlab 2010 software.

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 the variation of wind speed with height is the power law having the following form (Akpinar and Akpinar, 2005):

$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^m \quad (3)$$

where v_2 and v_1 are the mean wind speeds at heights h_2 and h_1 , respectively. The exponent m depends on such factors 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 (widely applicable to low surfaces and well exposed sites) (Akpinar and Akpinar, 2005).

Wind Power Density

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:

$$P = \frac{1}{2} \cdot \rho \cdot A \cdot V^3 \quad (4)$$

where P is the power density given in Wm^{-2} , ρ is the air density (kgm^{-3}) which depends on altitude, air pressure, and temperature, V is wind speed

(ms^{-1}) and A is the rotor area (m^2). In this work ρ is taken to be 1.225 kgm^{-3} .

The mean wind power density of the site can be expressed, again, by the following expression:

$$P = \frac{1}{2} \cdot EPF \cdot \rho \cdot v^3 \quad (5)$$

Energy Pattern Factor (EPF) is the ratio of the actual mean wind power density to the wind power density calculated using only the mean wind speed (Dahmouni et al., 2008):

$$EPF = \frac{1}{n\bar{v}^3} \sum_{i=1}^n v_i^3 \quad (6)$$

Annual Energy and Capacity Factor

Calculation of annual energy output requires knowledge of wind speed frequency distribution and the system power output of each turbine as a function of wind speed. The long-term wind speed distribution is combined with the power curve of the turbine to give the energy generated at each wind speed and hence the total energy generated throughout the year. Bin width of wind speed is usually 1 m/s. The general equation for calculating annual energy output is (Elmabrouk, 2009):

$$\text{Energy} = \sum_{i=1}^{i=n} P(U_i) H(U_i) \quad (7)$$

where $H(U_i)$ is the number of hours in wind speed bin U_i , and $P(U_i)$ is the power output at that wind speed.

Another measure is the capacity factor (CF) is defined as the ratio of the actual energy generated in a time period to the energy produced if the wind turbine had run at its rated power over that period. The capacity factor, is calculated as:

$$\text{Capacity factor (\%)} = \frac{\text{energy generated per year (KWh)}}{\text{turbine rated power (KW)} \times 8760} \times 100 \quad (8)$$

RESULTS AND DISCUSSION

The mean speed values at 10 m height are shown in Figure 1. Its ranges from 4.59 m/s to 6.69 m/s, for years, 2006, 2002, respectively. This figure also shows mean wind speeds at certain heights 20, 40, 50m. The mean wind speed for the overall eleven years was 5.53 m/s. Figure 2 shows the monthly variation of the average wind speed for the whole year at 10 m height. The wind speed for the whole year has the maximum monthly mean value of 6.38m/s which arises in August, while a minimum value of 4.49m/s occurs in November.

The wind power density calculated at different heights from Equations 5 and 6. The result is shown in Figure 3. This figure indicates that the maximum power density is 442.95 W/m^2 in 2002 and the overall mean power density is 242.72 W/m^2 at 50 m height. Also this figure shows the change of power density at various heights. Table 1 shows the annual mean wind speed, energy pattern factor (EPF) and power density

To determine Weibull frequency distribution and Weibull cumulative distribution, it is necessary to determine first the scale parameter (c) and the shape parameter (k). Using the Matlab 2010 software, the Weibull parameters were calculated using Maximum Likelihood Estimator (MLE) method. As shown (in Table 2), while the scale parameter varies between 4.81 (2006) and 7.39m/s (2001), the shape parameter ranges from 4.34 (2002) to 10.85 (2003) for the location analyzed.

Figure 4 shows the probability density of wind speed which drawn by using the values of scale and shape parameters with equation 1, from this distribution it is clear that the wind speed that has maximum frequency was 6m/s in (probability = 27.12 %). Figure 5 shows the Weibull cumulative distribution which gives the probability of wind speed exceeding the value of any given wind speed.

Following the attainment of the Weibull distribution parameters, the functions were applied to the power curve of Vestas V42-600 wind turbine estimate the capacity factor and the annual power production. The power curve and the main characteristics of Vestas V42-600 were shown in Figure 6 and Table 3, respectively.

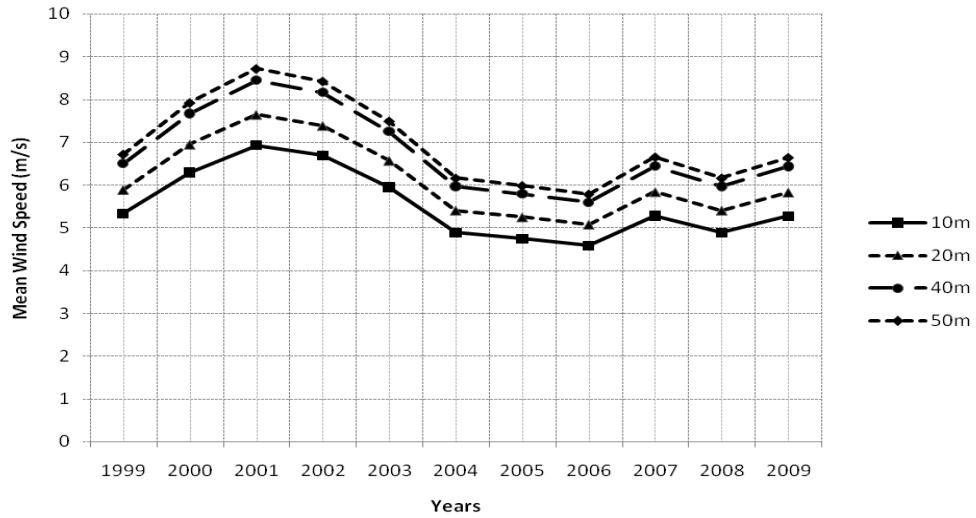


Figure 1: Variation of Annual Mean Wind Speeds with Height, (m/s).

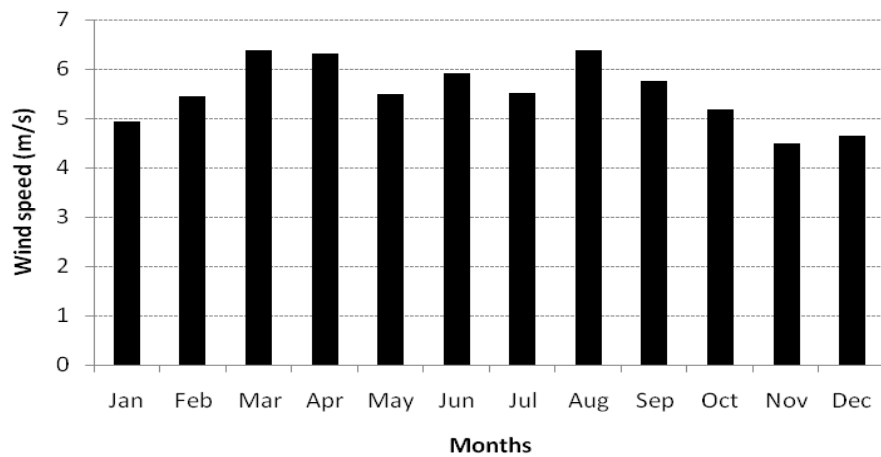


Figure 2: Variation of Wind Power Density with Height.

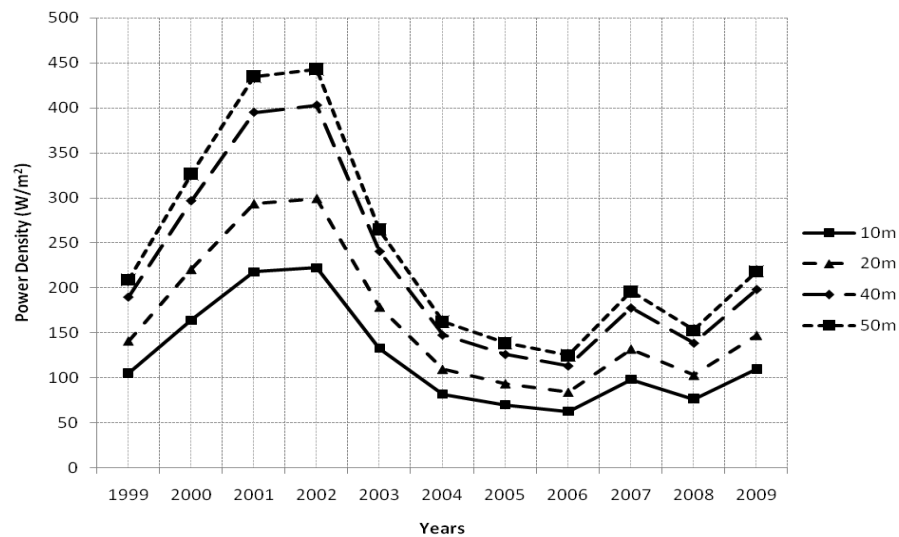


Figure 3: Variation of Wind Power Density with Height.

Table 1: Annual Average Wind Speed, EPF and Power Density.

Year	Annual Average wind speed (m/s)	EPF	Power Density (W/m ²)
1999	5.33	1.13	104.74
2000	6.29	1.07	163.64
2001	6.93	1.07	217.77
2002	6.69	1.21	222.08
2003	5.95	1.03	132.69
2004	4.89	1.14	81.43
2005	4.75	1.06	69.64
2006	4.59	1.06	62.58
2007	5.28	1.09	98.06
2008	4.89	1.07	76.54
2009	5.28	1.22	109.37

Table 2: Weibull Parameter.

Year	2001	2002	2003	2004	2005	2006
c	0.5158	0.4448	0.4689	0.6069	0.8125	0.2258
k	1.4108	2.6919	2.0007	2.4111	2.2531	2.2526

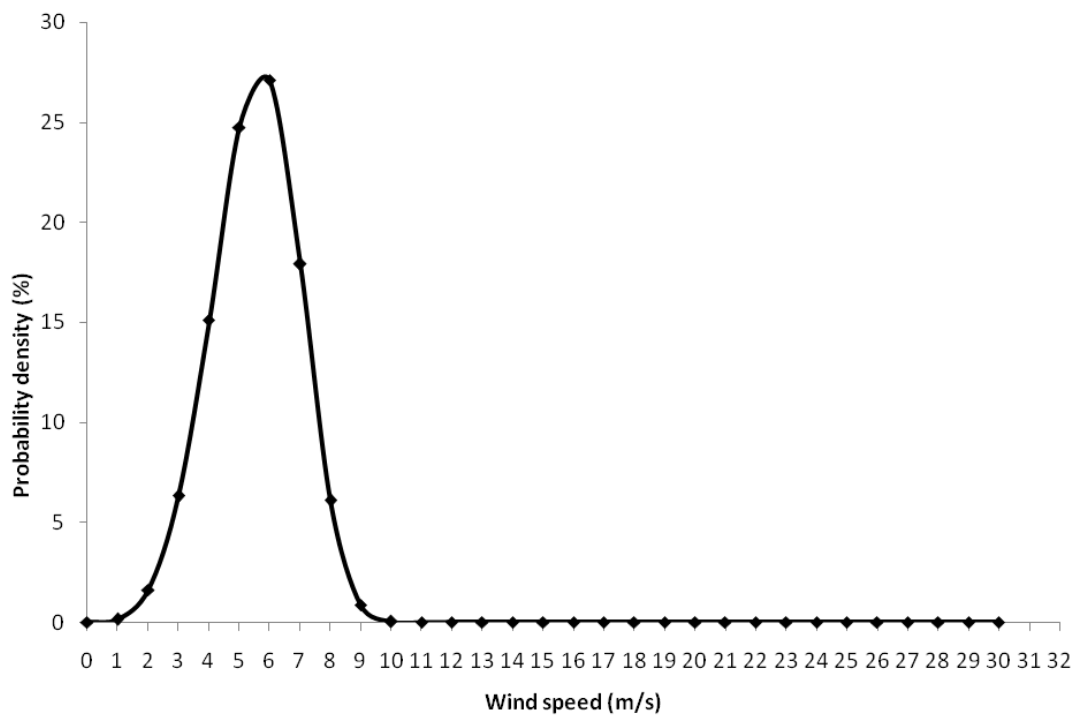


Figure 4: Weibull Probability Density Distribution.

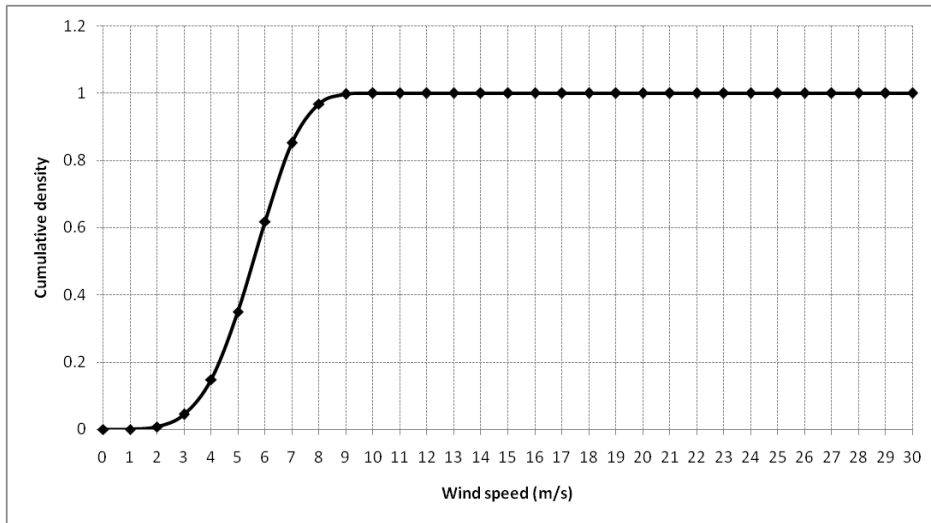


Figure 5: Cumulative Weibull distribution of Lagos.

Table 3: Main Characteristics of Wind Turbine used in this Study.

Turbine model	Vestas	V42-600
Rated power		600 kW
Tower height at hub		40 m
Rotor diameter		42 m
Swept area		1385 m ²
Number of blades		3
Cut-in wind speed		4 m/s
Rated wind speed		16 m/s
Cut-out wind speed		25 m/s

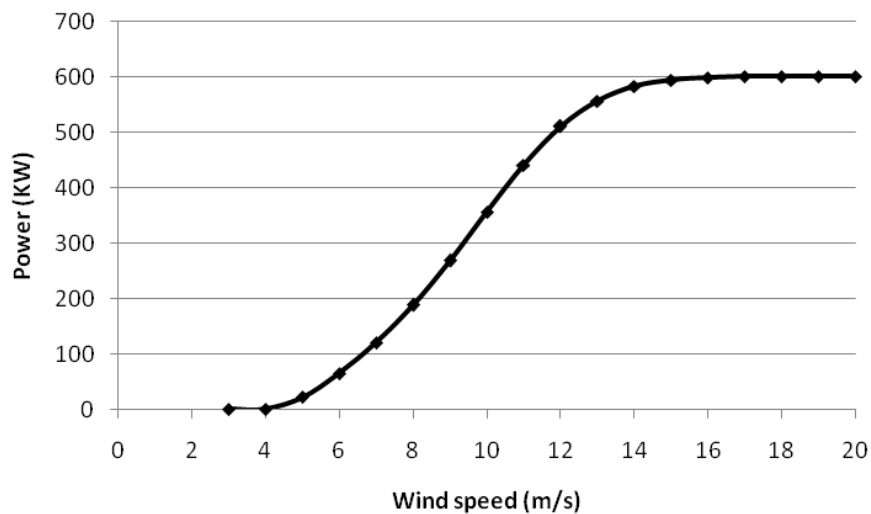


Figure 6: Power Curve of Vestas V42-600 Wind Turbine.

The power curves and Weibull probability distributions were evaluated at integer velocities between 0 and 20 m/s. In this way, the potential power output of these wind turbines were obtained independent of wind direction. The annual energy and capacity factor for the site are 512.11MWh and 9.7%, respectively.

CONCLUSION AND RECOMMENDATIONS

In this study, we have evaluated the wind energy potential in Lagos in southwestern Nigeria. This study shows that the wind energy is available in Lagos and it could be used to generate electricity. Existing data resources indicate that the mean annual wind of over 5m/s at Lagos with theoretical capacity factor of 9.7%. These values indicate that Lagos could generate 512.11MWh. This work should be extending to study the wind energy at different locations; this will help the resources in this field. The whole area of the country should be examined to detect the fields proper for the establishment of wind turbine farms, and public initiatives should start establishing wind energy farms in the selected areas.

REFERENCES

1. Akpinar, K.E. and S. Akpinar. 2005. "A Statistical Analysis of Wind Speed Data used in Installation of Wind Energy Conversion Systems. *Energy Conversion and Management*. 48:515 – 532.
2. Amusan, J.A., Y.K. Sanusi, and G.R. Fajinmi. 2007. "Determination of Annual Energy Capture Potential for Wind Power System: A Case Study". *Research Journal of Applied Sciences*. 2(9): 927 – 930.
3. Carta, J.A. and D. Mentado. 2007. "A Continuous Bivariate Model for Wind Power Density and Wind Turbine Energy Output Estimations'. *Journal of*

Energy Conversion and Management. 48(2):420 – 432.

4. Dahmouni, A.W., M.Ben Salah, F. Askri, F. Aloui, and S. Ben Nasrallah. 2008. "Wind Energy Potential in the Site of Borj-Cedria in Tunisia". *Revue des energies renouvelables CICME'08*. Sousse: 101 – 108.
5. Dorvol, A.S. 2002. "Estimating Wind Speed Distribution". *Energy Convers Manag*. 43(17):2311-8.
6. Eckaus, R.S. 1994. "Potential CO₂ Emissions: Alternatives to the IPCC Projections". Mimeo, MIT Joint Program on the Science and Policy of Global Change, August 1994.
7. Elmabrouk, A.M. 2009. "Estimation of Wind Energy and Wind in Some Areas (second zone) in Libya". *Renewable Energies*. March 2009.
8. Fadare, D.A. 2010. "The Application of Artificial Neural Networks to Mapping of Wind Speed Profile for Energy Application in Nigeria". *Journal of Applied Energy*. 87:934 – 942.
9. Mahyoub, H. and H. Albuhairei. 2006. "Assessment and Analysis of Wind Power Density in Taiz-Republic of Yemen". 10 (2006):12-21.
10. Ulgen K. and A. Hepbasli. 2002. "Determination of Weibull Parameters for Wind Energy Analysis of Izmir, Turkey". *Int J Energy Res*. 26:494–506.

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