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Analysis and Estimation of Wind Energy Potentials in Selected Locations in Kogi State, Nigeria.

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Abstract
The increasing energy demand, the rapidly depleting fossil fuel reserves and the environmental pollution associated its use has necessitated the development of alternative energy sources like wind energy for electricity generation. This work seeks to estimate the wind energy potential of Lokoja and Ayingba in Kogi state, Nigeria. The wind speed data for 6 years (2011 to 2016) from two ground stations (NIMET, Lokoja and CARNASRDA, Anyigba) was used for this study. This was used to analyze the wind energy potential and the economic viability of installing a wind turbine in these areas. Result shows that the monthly mean wind speed at a height of 50 m are 5.32 m/s and 2.38 m/s for Lokoja and Anyigba respectively. This suggest that wind energy generation would not be viable in Ayingba as it may be difficult to source a wind turbine whose cut-in speed would be compactable with the low wind pattern in this area. Analysis of the wind data of Lokoja shows that with a monthly average wind speed of 5.32m/s, 28157.76kWh of electric energy can be generated per annum. It is recommended that the wind turbine should have a power rating of 10-15kW, to be coupled to a 5kW permanent magnet 3-phase generator, connected in stand-alone configuration. Cost analysis shows that the proposed system is economically viable as the system would break even within a period less than ten years.

Keywords: Break Even, Economic Viability, Energy Potential, Wind Turbine, Generator

1. INTRODUCTION:

Energy is the most fundamental sector for the progression of a nation (Rifat & Mahzuba, 2014). It is inevitable for survival and indispensable for developmental activities (Bilal, 2013).

As the human population and activities are progressively developing, it is most certain that the demand for energy worldwide is increasing as well, and this trend is most likely to continue in the future (Abdullah, 2011). For meeting the expected energy demand as the population will rise and to sustain economic growth, alternative form of energy such as renewable energy needs to be explored (Khizir *et al*, 2012).

Renewable energy is one that is collected from renewable resources, which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat (Ellabban *et al*, 2014). Renewable energy otherwise known as green energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services. Of these green sources, the usage of wind as a source of energy is increasing in different parts of the globe due to rapid technological advancement. The main advantages of energy generation from renewable sources, such as wind, are the absence of harmful emissions, very clean and almost infinite availability of wind that is converted into electricity (Slootweg *et al*, 2001).

Wind is a classical example of a stochastic variable; due to this stochastic nature, wind energy cannot be controlled, but can be managed. This is because wind power is available only when the wind speed is above a certain threshold (Brady, 2009).

Analyses of available wind data for selected cities have confirmed a high prospect of wind energy resources in Nigeria. Several studies on renewable sources of energy have also been performed, worthy of mention here from these studies, however, is that the effective utilization of wind energy at a typical location requires sound knowledge of the wind characteristics and accurate wind data analysis. For example, the choice of wind turbine design must be based on the average wind velocity at a selected wind turbine installation site (Marcius-Kaitis *et al.* 2008). Studies have also shown that the wind flow patterns are influenced by terrains, vegetation, and water bodies (Oyedepo *et al*, 2012).

Although several studies as recorded by Osahenvemwen and Omorogiuwa (2009), Oluleye and Ogungbenro (2011), Vincent-Akpu (2012), Sanusi and Adedokun (2012), and Oluseyi et al. (2014) have been carried out to investigate the characteristics and pattern of wind speed across Nigeria, less attention has been given to sites in the north-central region. The focus of this study is, therefore, to evaluate the wind energy potential in selected locations in Kogi state in the North central region of Nigeria. This information will be helpful to the government and any organization in making an informed decision regarding investment in wind energy resource in this part of Nigeria.

2. MATERIALS AND METHODS:

2.1 Description of Research Location

Located in north-central geopolitical zone (also called middle-belt region) of Nigeria, Kogi State has a total land area of 28,313.53 square kilometers. The State is popularly called the Confluence State because the confluence of River Niger and River Benue is at its capital, Lokoja. The research areas chosen for this work is Lokoja Town (located in Lokoja Local Government Area and Anyigba Town (Located in Okura District in Dekina Local Government Area) all in Kogi State. These areas were chosen for the study partly due to the availability of ground station wind data from Nigeria Meteorological Agency (NIMET) located in Lokoja and the wind data for (Ayingba) sourced from the Centre for Atmospheric Research, National Space Research and Development Agency (CARNASRDA) situated in Ayingba.

2.2 Data Collection and Presentation:

Mean monthly wind speed data (in Knots) for six years (2011-2016) for Lokoja and Ayingba were sourced from NIMET and NASRDA respectively. These values were converted to their equivalent in meters per second (1 knot = 0.514 m/s) and the result is presented in table 1 and table 2. It is to be noted that these measurements were at height 6.1m and 10m for Lokoja and Ayingba towns respectively. These data were used to estimate the wind energy potential of the towns under review, select appropriate wind turbines, and determine the economic viability of the proposed system among other things.

Table 1: Mean Monthly Wind Speed (For Six Years) in m/s for Lokoja at height of 6.1m. (Source: NIMET, Lokoja.)

MONTH/ YEAR	2011	2012	2013	2014	2015	2016
Jan	1.54	1.54	0.92	0.71	0.92	1.58
Feb	1.54	1.64	1.98	1.84	1.73	2.04
Mar	1.02	1.53	1.68	1.48	2.96	1.94
Apr	1.53	2.04	2.30	2.65	2.14	2.09
May	1.54	1.54	2.40	2.14	1.33	1.98
Jun	1.54	1.63	1.84	1.28	0.92	2.19
Jul	1.53	1.54	1.28	2.50	1.17	1.43
Aug	1.54	1.54	1.73	2.40	2.09	1.53
Sep	1.54	1.54	1.28	1.28	1.53	1.94
Oct	1.33	1.53	1.28	1.43	1.68	1.98
Nov	1.54	1.54	0.97	1.38	1.84	1.84
Dec	1.02	1.02	0.87	0.97	1.84	1.58

Table 2: Mean Monthly Wind Speed (in m/s) (For Six Years) for Anyigba at height of 10m. (Source:NASRDA)

Months	2011	2012	2013	2014	2015	2016
Jan	1.26	1.25	1.19	1.07	1.53	1.45
Feb	1.37	1.33	1.21	1.23	1.28	1.16
Mar	1.44	1.32	1.24	1.43	1.35	1.36
Apr	1.35	1.58	1.17	1.37	1.36	1.36
May	1.26	1.28	1.19	1.15	1.37	1.27
Jun	1.10	1.20	1.23	1.24	XX	1.18
Jul	1.19	1.39	1.31	1.25	XX	1.17
Aug	1.16	1.29	1.09	1.27	XX	1.15
Sep	1.00	1.08	1.08	1.07	1.06	0.99
Oct	0.96	0.99	1.01	1.08	0.99	0.96
Nov	0.9	0.95	0.98	0.96	0.90	0.89
Dec	1.01	1.07	1.16	0.99	1.59	1.07

The cells marked **XX** indicates measurements were not taken for those months.

2.3 Data Analysis

Wind speed must be at the hub height of interest for wind power application; for this study, a tower height of 50m has been chosen. Therefore, the available wind speeds are adjusted to the wind turbine hub height using the power law expression given in equation 1 (Oyedepo *et al*. 2012);

$$v = v_{\text{ref}} \left[\frac{H}{H_{\text{ref}}}\right]^{\propto} \quad (1)$$

where

v= calculated wind speed

v_{ref} = measured wind speed

H = height at which wind speed is calculated

H_{ref} = height at which wind is measured

$\propto$= friction coefficient or Hellman exponent

Equation (1) was used to scale values of wind speed presented in tables 1 and 2. For example, from table 1, average wind speed for Lokoja town for the month of January = 1.201667 at height of 6.1m. Scaling this value to wind speed at a height of 50m, using equation (1), we have:

v_{ref} = 1.201667m/s (measured wind speed)

$v = v_{\text{ref}} \left[\frac{H}{H_{\text{ref}}}\right]^{\propto}$; = 1.201667x (50/6.1) x 0.4 = 3.941467 m/s.

This was done for January to December, for Lokoja and Ayingba. The results for Lokoja and Ayingba are presented in Table 3 and the chart of Figure 1.

Table 3: Computed Average Monthly Wind Speed (m/s) @ 50m height

	Average Monthly Wind Speed. (m/s) @ 50m height	
Months	**Lokoja**	**Ayingba**
Jan	3.94	2.58
Feb	5.89	2.53
Mar	5.80	2.71
Apr	6.97	2.73
May	5.98	2.51
Jun	5.14	2.38
Jul	5.17	2.52
Aug	5.92	2.38
Sep	4.98	2.09
Oct	5.05	2.00
Nov	4.98	1.86
Dec	3.99	2.30
Average wind speed	5.32	2.38

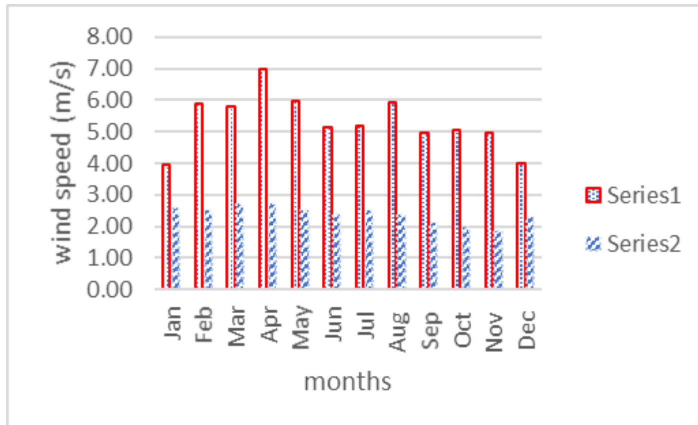

Figure 1: Bar Chart of Average Monthly Wind Speed (m/s) @ 50m height for Lokoja (series 1) and Ayingba (series 2)

Figure 1 shows that the wind speed for Lokoja is much higher than that of Ayingba whose wind speed can be as low as 1.86m/s (November). It will be difficult to source for a wind turbine whose cut in speed could be this low. It can be concluded that Ayingba town would not be a viable option for wind energy generation. The sections that follow would focus on Lokoja.

3 RESULTS AND DISCUSSION

3.1 Wind Power and Energy Estimation for Lokoja:

The wind turbine power is given by

$$P_T = \frac{1}{2}\rho A v^3 C_p \quad (2)$$

(Dai & Long, 2016).

where

P_T = wind turbine power in W

A = Cross sectional area of turbine blade interacting with air flow

ρ = density of air in kg/m^3 (taken as 1.225kg/m^3)

v =wind speed in m/s

C_p= power coefficient.

Wind electric energy in kWh is calculated using equation 3:

$$\text{Wind electric energy (kWh)} = \frac{\text{wind electric power}(w) \times \text{Time}(hr)}{1000} \quad (3)$$

Time = duration of flow of the energy in hours.

Using average monthly wind speed of 5.32m/s (table 3), wind turbine with blade diameter of 10m, power coefficient of 45% according to Ragheb and Ragheb (2011), wind electrical power and average monthly wind energy was determined as:

$P_e = \frac{1}{2}\rho A v^3 C_p$ = 0.5X 1.225X (3.142 x 5^2) x $(5.32)^3$ x 0.45 = 3259.87W = 3.259kW.

Average Wind Energy generated per month = $\frac{\text{wind electric power}(w) \times \text{Time}(hr)}{1000}$ = 3259.87 x 24 x 30/1000 = 2347.1kWh.

Using the average monthly wind speed from table 3, the Average monthly energy generation from wind turbine (at Height of 50m) was computed, the result is presented in the bar chart of figure 2.

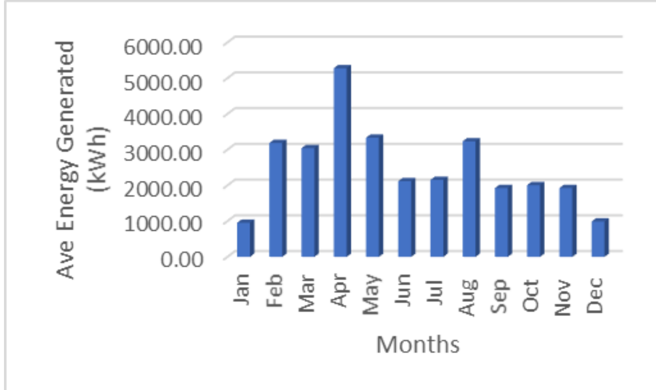

Figure 2: Average Monthly Energy Generation from Wind Turbine (At Height of 50m) for Lokoja.

Annual average wind electrical energy to be generated the wind turbine =
2346.48 x 12 = 28157.76kWh/per annum.

3.2 Determination of Wind Turbine Capacity:

Wind turbine has capacity factor values between 20% - 40% (United States Energy Information Administration (USEIA), 2009).

Calculated electric power = 3.259 kW

Using a capacity factor of 0.35

Turbine power = $\frac{3.259}{0.35}$ = 9.3kW

From the above calculated power of 9.3 kW, selecting a wind turbine capacity of 10-15kW with a blade diameter of 10m will be suitable for the area. Care must be taken ensure that the cut-in speed of the turbine selected is lower than the values presented in table 2. The selected wind turbine can be connected to a 5kW (because of low efficiency of wind turbines) 3-phase permanent magnet ac generator in a standalone configuration.

3.3 Economic Viability Analysis of the Proposed System:

The cost components of the proposed system include:

i. Total Capital Cost (cost of wind turbine + generator + Installation + Civil works + electrical infrastructure etc.)
ii. Operation and Maintenance cost

According to Mathew (2012), the wind turbine cost takes 65% of the total capital cost, while the installation cost takes 35%. The operation and maintenance cost per annum is 1.5% of the wind turbine cost (Ragheb, 2015). Since wind is free, the fuel cost is zero.

Average Cost of 10-15kW wind Turbine = $2500.00 (https:m.madeinchina.com)

Average Cost of 5kW PM 3-Phase generation = $1400.00 (www.m.alibaba.com)

Cost of shipment (10% of purchase Price) = $390.00

Total $4290.00

Therefore, Total Capital Cost = $4290/0.65= $6600.00

Operation and Maintenance Cost (1.5% of $4290.00) = $64.35

Total Cost of Implementing the proposed system = $6600.00 + $64.35 = $6664.35.

As of September 2018, the Central Bank of Nigeria (CBN) approved exchange rate is ₦360 to $1. Therefore, Total Cost of Implementing the proposed system in Naira =

6664.35 x 360 = ₦2,399,166.00.

The annual average wind electrical energy that can be generated by the proposed turbine has earlier been determined to be 28157.76kWh per annum. According to Nigerian Electricity Regulatory Commission (NERC), 1kWh of electricity cost ₦24.29 in Kogi State. (NERC MYTO, 2015).

Therefore 28157.76kWh would cost: 28157.76 x 24.29 = ₦683,951.99

Comparing this amount (₦683,951.99) with total cost of implementing the proposed system (₦2,399,166.00.), the proposed system will break even within a period less than 10 years, even if other cost components (cost of Land, community issues etc.) are considered. This is economically viable as average useful service of a wind turbine is 20 years (Ragheb & Regheb, 2011).

4. CONCLUSION:

The research has shown that there are indeed wind energy generation potentials in Lokoja, Kogi State, Nigeria. It is suggested that a wind turbine be installed in a suitable location in Lokoja, this could serve as energy source for streetlights and other low power applications. The wind turbine should have a power rating of 10-15kW, to be coupled to a 5kW permanent magnet 3-phase generator, connected in stand-alone configuration. Care must be taken to ensure that that cut-in speed of the turbine selected matches with the average wind speed in Lokoja.

Cost analysis shows that the proposed system is economically viable as the system would break even within a period less ten years. This break-even period is reasonable as wind turbines are estimated to have useful service life of about 20 years.

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