American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-12, Issue-5, pp-80-85
www.ajer.org
Research Paper Open Access

Wind Energy Potential for Domestic Electricity Supply in Buildings: A Case Study

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Abstract
This paper examines the wind energy potential of Calabar and the cost of investment using wind data obtained from Calabar. The Weilbull parameters were analyzed measured at 10 m hub height. Wind speeds at varying hub heights were calculated by extrapolating the wind data at 10 m height using location wind shear exponents. The annual average wind speed, k *and* c *values were between* $1.91 \le v_{am} \le 5.213$ *m/s,* $1.733 \le k \le 6.203$ *and* $2.13 \le c \le 5.535$ *m/s respectively for hub heights varying from 10 to 120 m. The yearly average power density (APD) was less than 100 W/m*^{2} *showing Calabar is not suitable for grid-connected applications but will be adequate for off-grid wind driven systems. This can power some household appliances like, television, VCD, DVD, fans, water pump, vacuum cleaners, battery charger and air conditioning systems.It can be inferred that at 120 m hub height Calabar is placed under class 2 or less category.Thus, fit for the appliances earlier mentioned.*

Keywords:*Building, Calabar, Energy, Weilbull, Wind power.*

Date of Submission: 01-05-2023 Date of acceptance: 10-05-2023

I. Introduction

Wind energy appears to be the most attractive renewable energy sources in the world because of its advantage of being a clean, sustainable and eco- friendly energy source [1]. For these reasons and coupled with the rate of depletion of conventional energy resources due to exploitation, most countries of the world have sought for alternative energy resources such as solar, hydropower, geothermal, wind power and biomass. Wind energy development and utilization tops the agenda of some countries in Europe, Asia, America and few countries in Africa [2,3].

Nigeria have high potentials of wind energy, but the rate of exploration is low as they exist no record of wind power plants linked to the nation grid system making its contribution to the overall energy consumption mix inconsequential. The world population is increasing daily with developing countries topping in growth rate. Consequently, the increase in population, living standards and economic activities has added to the global increase in energy demand. Due to insufficient energy supply especially, for some developing economies with uneven energy structure has led to increase import dependence and slowed industrialization [4,5]. Nigeria is faced with this problem of imbalance in her internal energy demand. Despite her dominant of fossilfuels in the energy mix structure the country is still unable to provide sufficient energy to drive her economy.

Furthermore, statistics show that only 40% of the country's poupulation have access to grid electricity while the remaining 60% largely rural settlers depends on biomass and firewood to meet their energy demand [5]. The consequence of the latter energy sources is deforestation, environmental degradation and increase in greenhouse emissions. A condensed energy mix system with renewable energy having a high percentage in the energy mix will be a good measure to solving the internal energy problem. The potential of wind energy capacity in different locations in Nigeria have been studied. The highest wind viability is found in the Northeast and Northcentral regions of the country [6]. Little literature exists on wind characteristics in the south south region where Calabar is located. This research paper therefore, presents a feasibility study on the wind energy potential in the city of Calabar in Cross River State for electricity supply in buildings.

II. Description of Calabar location

Calabaris an ancientcity in Nigeria and the administrative headquarters of Cross River State. The city is located at 4.95° North latitude,8.32° East longitude and 99 meters above the sea level. The city has about 461796 inhabitants with an area of 406 km². For ease of administration, the city is divided into Calabar South LGA and Calabar Municipal as shown in Figure 1. The city has a large crude oil and limestones deposits. It is bordered to the west by Akwa Ibom state, to the east by the Republic of Cameroon and Equatorial Gunnie and to the south, the Atlantic ocean [7]. The wind data for the location were obtained from NIMET station in Calabar for a period of ten years. At the inception of the study, we had made some assumptions before the actual analysis was conducted. However, we have assumed the city to have a good wind capacity to be harnessed for varied applications and for even commercial purposes. The obtained data were then processed, and the wind power density and other wind characteristics were calculated which assisted in the discussion of our assumption.

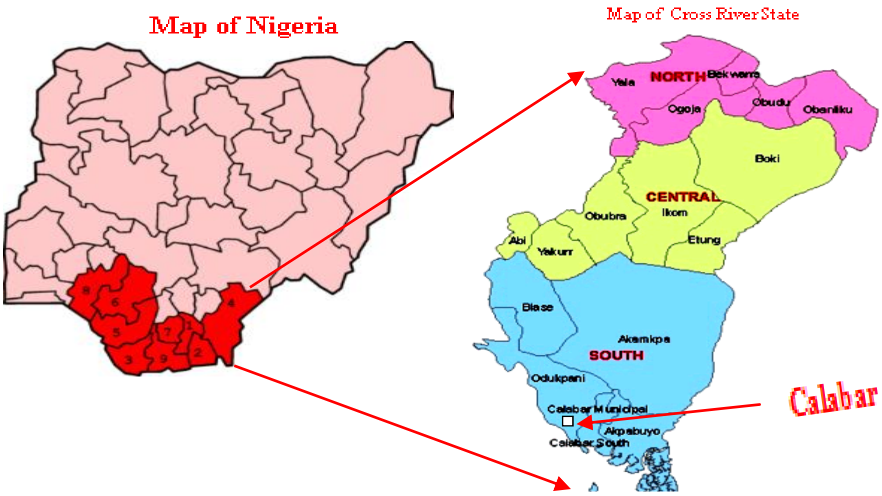

Figure. 1 Map of Nigeria showing

III. Methods and analysis

3.1 Wind characteristic equations

The Weibull distribution function (WDF) is adopted in this work for describing the distribution of wind speed. The two-parameter common form of Weibull distribution probabilityfunction and the corresponding cumulative probability function are expressed mathematically in equations (1) and (2) [8].

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

(1)

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

(2)

Where $f(v)$ is the probability of observing wind speed (v), k is the dimensionless shape parameter, c is the Weibull scale parameter (m/s), $F(v)$ is the cumulative probability function of the observing wind speed (v). The Weibull shape factor k of a specific wind site shows how peaked the wind distribution is and also typifies the wind potential of the location while the scale parameter c, shows how windy a wind location is. The values of k and c are determined by the following approximations [8].

$$k = \left(\frac{\sigma}{v_m}\right)^{-1.086} \qquad (1 \leq k \leq 10)$$

(3)

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

Where:

σ, v_m and $\Gamma(x)$ are the standard deviation, average wind speed and gamma function of (x) respectively, calculated as in[5]. The wind power density is an important factor when assessing wind potential of a particular location. It describes the available quantity of energy over unit of time and swept area of the blade available for a chosen area for conversion to electricity by a wind turbine system. Equations used in estimating wind power and the wind power density based on Weibullprobability density function are presented in[5].Wind speed are normally measured at a reference height (h_0) different from the turbine hub height. Wind speed at the reference height (h_0) can be extrapolated to different turbine height (h) by using the power law expression in [8].

IV. Results And Discussion

4.1 Wind speeds and Weibull distribution parameters

The mean monthly wind speed variations at different hub heights from (10 to 120m) are depicted in Figure 2 for Calabar. The average wind speeds from (2002 to 2011) are evaluated first by obtaining the average of all the available wind speeds in a month at 10m. Other wind speeds obtained at higher altitudes are extrapolated based on data calculated from the reference heig (h_0). The monthly average wind speed lies between 1.58 $\leq v_{mm} \leq$ 5.97 (m/s) for hub heights varying from 10 to 120 m. The highest wind speed occurs in the month of February at 120 m hub height, and the lowest wind speed occurs in the month of December at 10 m hub height. This implies that Calabar may not be feasible for enlarged annual electricity production especially at lower altitudes because of the cost factor. The wind potentials can instead be utilized in low energy system applications.

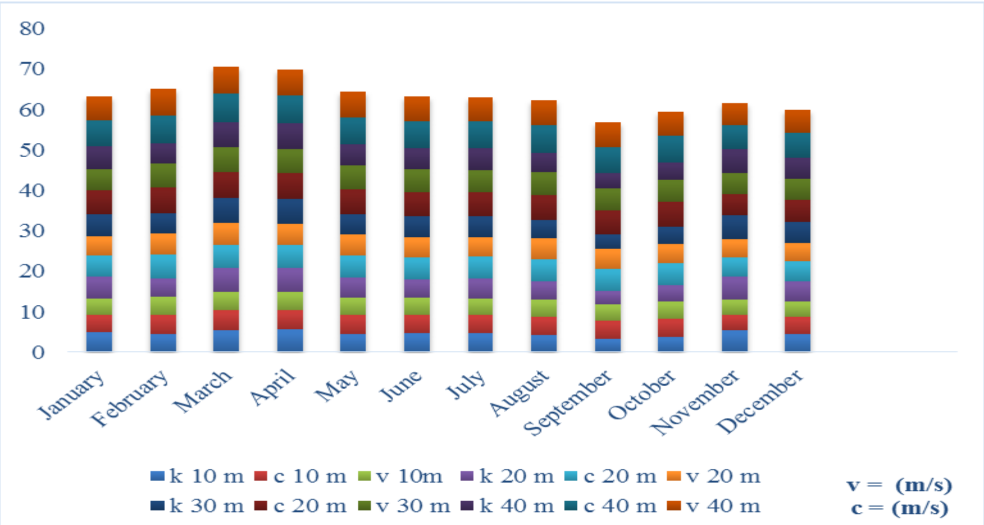

Fig. 2. Wind parameters at different turbine heights

4.2 Wind power and energy density

The monthly average wind power density (APD) and average energy density (AED) for hub heights varying from 10 to 120 m are presented in Table 1. The monthly APD and AED varies from 2.40 W/m^2 to 129 W/m^2 and 1.79 kWh/m^2 to 86 kWh/m^2 respectively. The minimum and maximum values of APD and AED occurs in the months of December and February respectively. Table 4 presents the annual average mean power density and the annual energy for hub height difference of 10 and 120 m. The annual average APD varies from

4.41 to 87.42 $W/m^2/year$ while the annual energy varies from 38.42 to 762.3 $kWh/m^2/year$. Other yearly wind characteristics, v_{mp}, $v_{\max E}$, k and c are also summarized in Table 2

Table 1
Mean monthly average power and energy densities at respective hub heights

Height (m)	10m (h_O)		40m		60m		80m		100m		120m	
Month	APD (W/m^2)	AED (kWh/m^2)	APD (W/m^2)	AED (kWh/m^2)	APD (W/m^2)	AED (kWh/m^2)	APD (W/m^2)	AED (kWh/m^2)	APD (W/m^2)	AED (kWh/m^2)	APD (W/m^2)	AED (kWh/m^2)
January	4.71	3.51	20.33	15.13	34.02	25.31	50.18	37.33	68.98	51.32	90.53	67.35
February	7.71	5.18	30.65	20.59	50.77	34.12	73.56	49.43	99.62	66.94	129.1	86.77
March	4.80	3.57	20.26	15.07	34.53	25.69	50.87	37.85	69.92	52.02	91.61	68.16
April	5.03	3.62	21.33	15.36	66.53	47.9	64.35	46.33	87.65	63.1	114.1	82.12
May	4.50	3.35	13.61	10.13	32.78	24.39	48.40	36.01	66.66	49.59	87.60	65.17
June	6.28	4.52	25.39	18.28	42.96	30.93	62.69	45.14	85.41	61.50	111.3	80.16
July	3.18	2.36	14.11	10.50	26.27	19.55	39.22	29.18	54.44	40.50	72.01	53.57
August	3.43	2.55	15.11	11.24	27.34	20.34	39.33	29.26	54.47	40.53	72.05	53.61
September	4.43	3.19	18.69	13.46	32.37	23.30	47.83	34.44	65.91	47.45	86.90	62.57
October	3.94	2.93	17.39	12.94	29.44	21.91	43.71	32.52	60.40	44.94	79.64	59.25
November	2.57	1.85	11.99	8.631	20.81	14.98	31.37	22.59	43.93	31.63	58.54	42.15
December	2.40	1.79	11.04	8.216	19.66	14.63	29.73	22.12	41.70	31.02	55.68	41.43

APD = average power density, AED = average energy density

Table 2
Whole year wind characteristics at respective hub heights

Hub height (m)	k	c **(m/s)**	v_{mp} **(m/s)**	$v_{\max E}$ **(m/s)**	v_{am} **(m/s)**	**Average mean power density ($W/m^2/year$)**	**Annual energy ($kWh/m^2/year$)**
10	3.391	2.133	1.924	2.445	1.910	4.41	38.42
40	3.862	3.498	3.183	3.833	3.087	18.33	159.55
60	4.031	4.036	3.758	4.457	3.809	34.79	303.05
80	4.150	4.577	4.283	5.032	4.277	48.44	422.20
100	4.252	5.079	4.769	5.561	4.759	66.59	580.42
120	4.577	5.535	5.242	5.995	5.213	87.42	762.31

4.3 Wind energy classification

A classification as shown in [9] indicates that the wind energy capacity in Calabar can be placed under class 2. Based on the wind classification by [9](Table 3), it can be inferred that Calabar at 120 m hub height as shown in Figure 2 and Table 1 are placed under class 2 or less category. The wind pattern shows that the city is not suitable for extensive wind turbine installation. However, the wind power can be utilized for varied applications like water pumping, lightings, electric fans and supply of intermittent power for low-energy utilization systems.

$$\begin{cases} \frac{P}{A} < 100 \text{ W/m}^2 \text{ is poor} \\ \frac{P}{A} \approx 400 \text{ W/m}^2 \text{ is good} \end{cases} \quad (5)$$

$$\frac{P}{A} > 700 \text{ W/m}^2 \text{ is great}$$

$$\begin{cases} \text{fairly } (\text{P, W/m}^2 < 100) \\ \text{fairly good } (100 \le \text{P, W/m}^2 < 300) \\ \text{good } (300 \le P, 300 \text{ W/m}^2 < 700) \\ \text{very good } (P, \text{W/m}^2 \ge 700) \end{cases} \quad (6)$$

Table 3
Wind power classification for 50 m elevation [9]

Wind power class	Potential	Wind power density (W/m^2)	Wind speed (m/s)
1	Poor	0-200	0.0-5.6
2	Marginal	200-300	5.6-6.4
3	Moderate	300-400	6.4-7.0
4	Good	400-500	7.0-7.5
5	Excellent	500-600	7.5-8.0
6	Excellent	600-800	8.0-8.8
7	Excellent	More than 800	More than 8.8

V. Conclusions

Feasibility study of wind energy investment for prospective electricity supply in Calabar has been investigated. The following conclusion can be made from the results obtained.

(1) The monthly and annual average wind speed lies between $1.58 \le v_{mm} \le 5.97$ m/s $1.91 \le v_{am} \le 5.213$ m/s for hub heights varying f 10 to 120 m. The highest wind speed occurs in the month of February at 120 m hub height, and the lowest wind speed occurs in the month of December at 10m hub height.

(2) The monthly and annual average values of k and c lie between $2.396 \le k \le 6.483$, $1.733 \le k \le 6.203$ m/s and $3 \le k \le 3.86$, $2.133 \le c \le 5.535$ m/s respectively, at hub height varying from 10 and 120 m.

(3) The monthly APD varies from 2.40 W/m^2 at 10m to 129 W/m^2 at 120 m while AED values varies from 1.79 kWh/m^2 at 10 m to 86 kWh/m^2 at 120 m. Maximum and minimum values of APD and AED occurs in the months of February and December respectively. The annual energy varies from 38.42 to 762.3 $kWh/m^2/year$ with annual mean average energy between 3.21 and 63.52 $kWh/m^2/year$. While the annual APD varies from 4.41 to 87.42 $W/m^2/year$ at the considered hub height variation.

(4) The annual computed APD values at the considered hub heights were less than 100 W/m^2 which means Calabar corresponds to (class 1) wind power. This is also an indication that Calabar is not suitable for grid-connected applications. The available energy may be suitable for low energy system applications like, lighting, water pumping, battery charging,VCD, DVD and airconditioning units

(5) The study shows that small scale wind turbine projects are achievable in Calabar city and therefore recommends the installation of small size wind turbines for electricity generation and distribution to houses for sustainable development.

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