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Wind Energy Potential Assessment of Yola

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Abstract- **This report present an assessment of wind energy potential of Yola town, the Adamawa State capital based on the Weibull Model using 15yaers mean monthly wind speeds covering (1986-2000) taken at height of 10m. Power densities were found to range from 0.594Wm^{-2} in November to 2.802Wm^{-2} in April and energy density was found to range from 0.442kWhm^{-2} to 2.082kWhm^{-2}. Principles of extrapolation were applied at a height of 30m using roughness of 0.214. Power and energy densities at this height, were found to range from 1.203Wm^{-2} to 5.672Wm^{-2} and 0.894kWhm^{-2} to 4.215kWhm^{-2} respectively. Weibull's distribution parameters k, c and Γ functions were also computed and their average values were 2.537, 1.408ms^{-1} and 0.634 respectively. The Assessment reveals that Yola is not a good zone for generation of electrical energy from wind. However, it can be suitable for wind mills for water pumping and grinding or milling pulses and grains.**

Keywords- **Wind, Speed, Energy, Power and Weibull Model**

I. INTRODUCTION

Wind resources are one of the more promising of the alternative sources of energy currently under study and are one of the few whose large application has been proven. Wind is a flow of air and the air has certain mass and density. Wind as a flow of air has kinetic energy, hence wind is a natural source of kinetic energy. Energy in the wind can be converted into useful mechanical energy by means of wind turbine, wind mill and sails for ships etc (Grogg, 2005). The generation of electrical power from mechanical energy sources requires the careful matching of the source characteristics with those of the electrical grid. Wind energy presents additional challenges in that the source is highly variable. Current solutions to this problem, including active blade pitch control and power conditioning, have proven to be effective, but with additional cost (Gardner et al, 2007).

According to (Grogg, 2005) Wind energy is one of the most cost effective of all types of renewable energy. It does not create pollution or waste as does the fuel, wind is not used faster than it is produced. However, to make wind a viable source of energy (electricity in particular) careful design of wind-capturing machines is necessary. Currently, wind energy is one of the least expensive of the alternative/renewable energy sources and is becoming more affordable as the technology improves and infrastructure develops. Wind energy comprises only a small amount of the total energy that reaches the earth. About 1.74 x 10^{17}Watts of power from the sun contact the earth each year this is 160 times the total energy in the world's reserves of fossil fuels. Only a small portion, 1-2%, goes into the formation of wind (about 100 times the power that is stored in plants). Wind develops when the sun's rays unevenly heat the air in the atmosphere. The majority of heating occurs at the equator, which receives the most direct rays. These rays warm the equator air, which rises and moves north and south to the cooler regions. The air in the northern and southern hemispheres flows into the low-pressure area created at the equator by the rising hot air. At the same time, the earth is spinning creating a Carioles force that shifts moving particles, such as the air, to the right in the northern hemisphere and left in the southern hemisphere. The uneven heating and the Carioles forces together create the geostrophic winds, which are 1km above ground and are the overall prevailing winds in each region.

Grogg, (2005) also explained that Geostrophic winds only give a very general idea of the direction of the wind at each latitude. At a given site, the elements of the landscape; hills, valleys, bodies of water, and other obstacles etc, have a significant effect on winds as high up as 100m, although the upper atmosphere winds can pull along the lower winds and give them more power. Mojeed, (1997) considered 10yrs (1986-1995) hourly and daily wind speeds of some selected citiesin the north-east and north-west of Nigeria. He found that weibull and exponential probability distribution models were the best fit for most sites. He also found that theoretical power densities range from 5.71Wm^{-2} in Bauchi and 113Wm^{-2} in Kano.

II. METHODOLOGY

The interaction between the wind and the roughness of the ground is known as wind shear. Shear is essentially friction on a large scale, but because air is not a rigid body, the air closer to the ground is affected more than that higher up. The velocity increases with height, as it becomes less affected by the roughness friction:

$$V \propto \ln(z/z_o) \qquad (1)$$

Where V is the velocity, z is the height, and z_o is the roughness, essentially proportional to the overall height of the terrain (from 10^{-4}m over water to 1m in cities). Because the wind speed increases with height, wind turbines are mounted on high towers, although the height of an actual tower is limited by structural concerns and cost.

Wind energy is non uniform, intermittent, erratic form of energy and its speed in the range of 4ms^{-1} to 30ms^{-1} are considered suitable for driving wind turbine generator shaft for producing electrical energy (Rao and Paruleker, 2004). The power P in the wind is given by

$$P \propto V^3 \qquad (2)$$

Also

$$P \propto A \qquad (3)$$

Where V is the wind speed and A is the area under consideration. Wind velocity increases with height above ground and the favourable wind sites are generally away from forests, cities and hill. Sites such as deserts, flat vacant land, on-shore/off-shore and top of hills etc are considered favourable.

2.1 Features of the Study Area

Yola, the Adamawa state capital occupies a geographical location around longitude 12.47°E and latitude 9.23°N at an elevation of about 186m. it is located by the river Benue bank closed Girei Hill.

2.2 Data Collection and Analysis

In this work fifteen years (1986-2000) monthly mean speeds data at a height of 10m for Yola were obtained from the Nigerian Metrological Agency (NIMET) Oshodi Lagos. These data were statistically analysed based on weibull's model. Weibull's parameters were determined which include probability density function, duration function, shape factor k, scale factor c and the gamma function Γ. Power densities and energy densities were then evaluated.

2.3 Mean monthly wind speed and standard deviation

Mean monthly wind speed and standard deviation were obtained using equations (4) and (5) respectively

$$V_m = N^{-1}[\sum_{i=1}^{N} V_i] \qquad (4)$$

$$\sigma = [\frac{1}{N-1}\sum_{i=1}^{N}(V_i - V_m)^2]^{1/2} \qquad (5)$$

Were V_i is the individual velocity, V_m is the mean velocity and N the number of measurement (Brower et al, 2010).

2.4 Wind Speed Probability Distribution.

For ease of statistical analysis the fifteen years mean speed were arranged in to a class interval for each month and their class centers are represented in table 1. The wind speed probability distribution is essential in wind energy analysis and could be used to evaluate the capacity factor for a particular wind turbine generator used in producing any form of energy. The probability for the wind speed to lie in certain interval or duration especially when the speed is above the cut in speed of the turbine and the mean power density depend on certain parameters. The weibull's probability distribution is characterised by three parameters

i. Dimensionless shape parameter k.
ii. The scale parameter c (m/s).
iii. Gamma function Γ.

(Putnam, 1948) Showed that

$$k = (\frac{\sigma}{V_m})^{-1.09} \qquad (6)$$

$$c = V_m[\frac{k^{2.6674}}{0.184+(0.816k^{2.73859})}] \qquad (7)$$

$$\Gamma = \frac{V_m * k}{c(k+1)} \qquad (8)$$

2.5 Wind Power and energy estimation

According to (Betz, 1942) and equations 2 and 3, the specific power available in a cross-sectional area (A) perpendicular to the wind stream moving at a speed V_m expressed as power per unit area is giving by

$$\frac{P}{A} = \frac{1}{2}\rho V_m^3 \ (Wm^{-2}) \qquad (9)$$

Where ρ is the standard air density ($1.225kgm^{-3}$)

Also energy per unit area is giving as:

$$\frac{E}{A} = \frac{1}{2}\rho V_m^3 * t \ (kWhm^{-2}) \qquad (10)$$

Where t is the active hours and given by 742.857hours.

III. RESULT AND DISCUSSION

From the equations 4 to 10, table 1 was produced

Table 1: Mean monthly weibull's parameters and power and energy densities for 10m height.

Month	V_m (ms^{-1})	σ (m/s)	K	c (m/s)	Γ	P/A (Wm^{-2})	E/A ($kWhm^{-2}$)
January	1.21	0.41	3.253	1.351	0.685	1.085	0.806
February	1.26	0.53	2.570	1.420	0.639	1.225	0.910
March	1.50	0.7	2.295	1.693	0.617	2.067	1.536
April	1.66	0.65	2.779	1.866	0.654	2.802	2.082
May	1.57	0.72	2.339	1.772	0.621	2.370	1.761
June	1.42	0.48	3.262	1.586	0.685	1.754	1.303
July	1.30	0.56	2.504	1.466	0.634	1.346	1.000
August	1.00	0.44	2.447	1.128	0.629	0.613	0.455
September	1.03	0.45	2.466	1.162	0.631	0.669	0.497
October	1.07	0.49	2.343	1.208	0.621	0.750	0.558
November	0.99	0.66	1.556	1.101	0.547	0.594	0.442
December	1.02	0.42	2.630	1.149	0.643	0.650	0.483

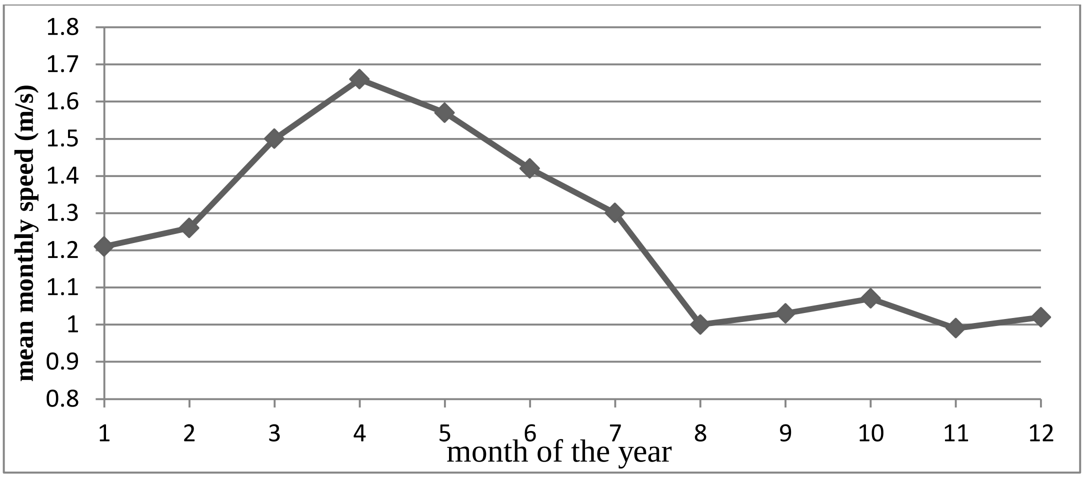

Figure 1: Variation of mean monthly speed at the height of 10m

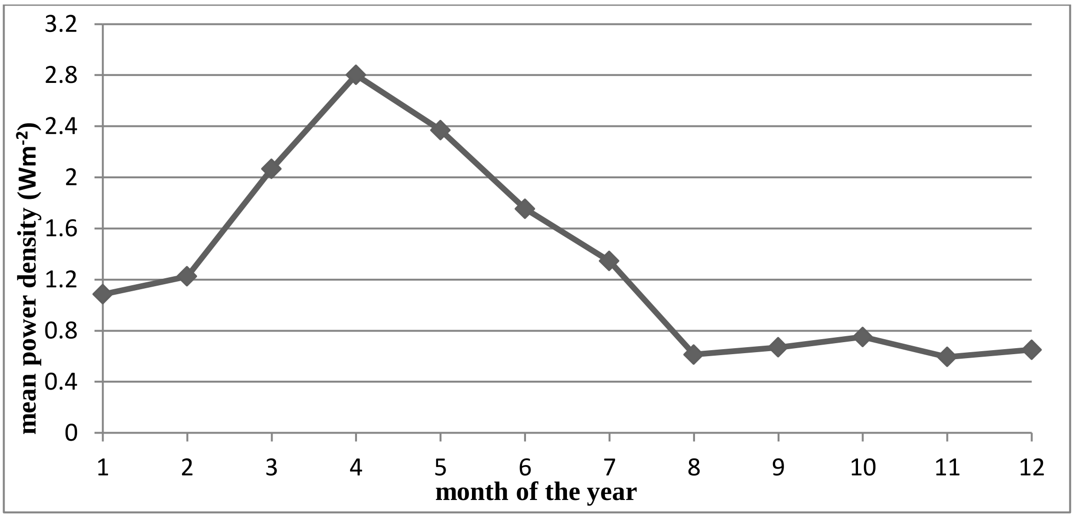

Figure 2: Variation of mean monthly power density at the height of 10m

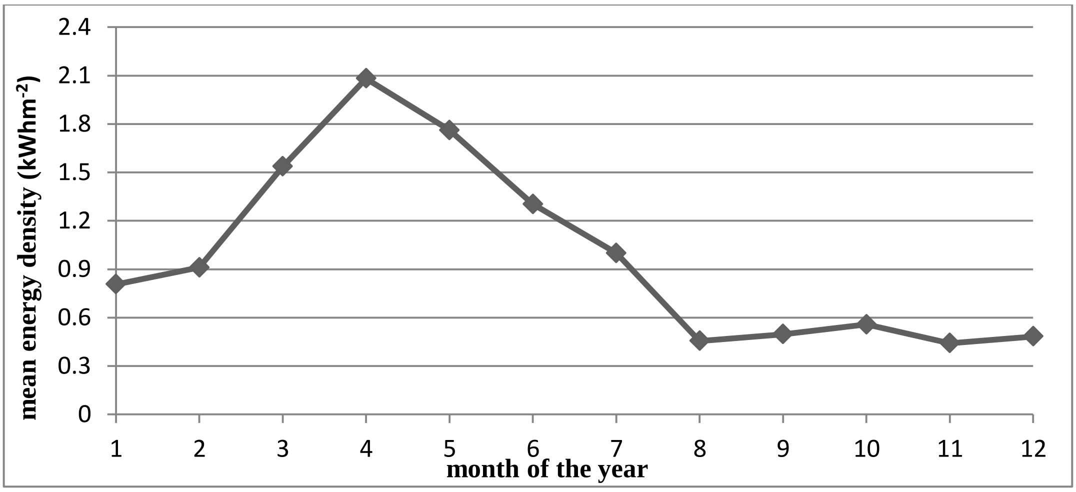

Figure 3: Variation of mean monthly energy density at the height of 10m

3.1 Extrapolation of Wind Power at a height of 30m

Vertical extrapolation was carried out on the wind speeds in order to improve the power density of area using the relation in equation 11 (Rai, 2010) and was used together with equations 9 and 10 to produce table 2 below

V_h=V_10 (〖h/10)〗^n (11)

Where V_hthe wind speed at the new height h and n is is terrain roughness (0.214) for Yola.

Table 2: Power and energy densities of the mean wind speed at a height of 30m

Month	V_{30} (ms^{-2})	P/A (Wm^{-2})	E/A ($kWhm^{-2}$)
January	1.531	2.197	1.632
February	1.594	2.480	1.843
March	1.898	4.185	3.110
April	2.100	5.672	4.215
May	1.986	4.799	3.566
June	1.796	3.550	2.638
July	1.645	2.724	2.024
August	1.265	1.240	0.921
September	1.303	1.355	1.007
October	1.354	1.519	1.129
November	1.252	1.203	0.894
December	1.290	1.316	0.978

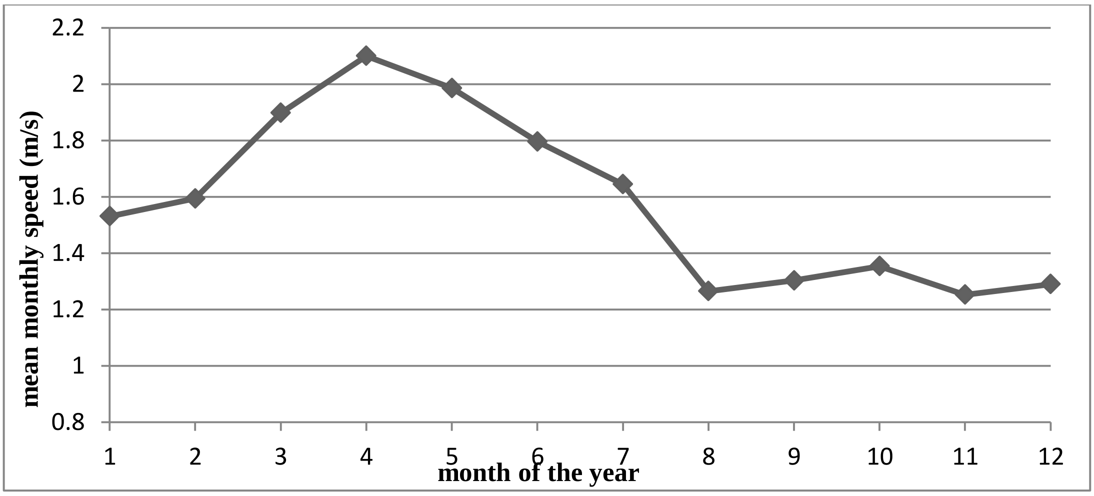

Figure 4: Variation of mean monthly speed at the height of 30m

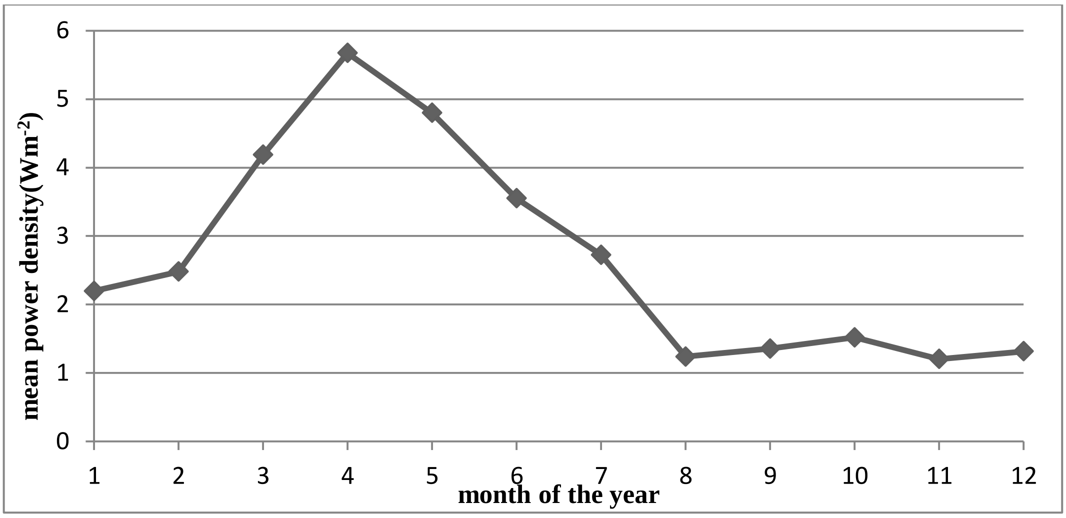

Figure 5: Variation of mean monthly power density at the height of 30m

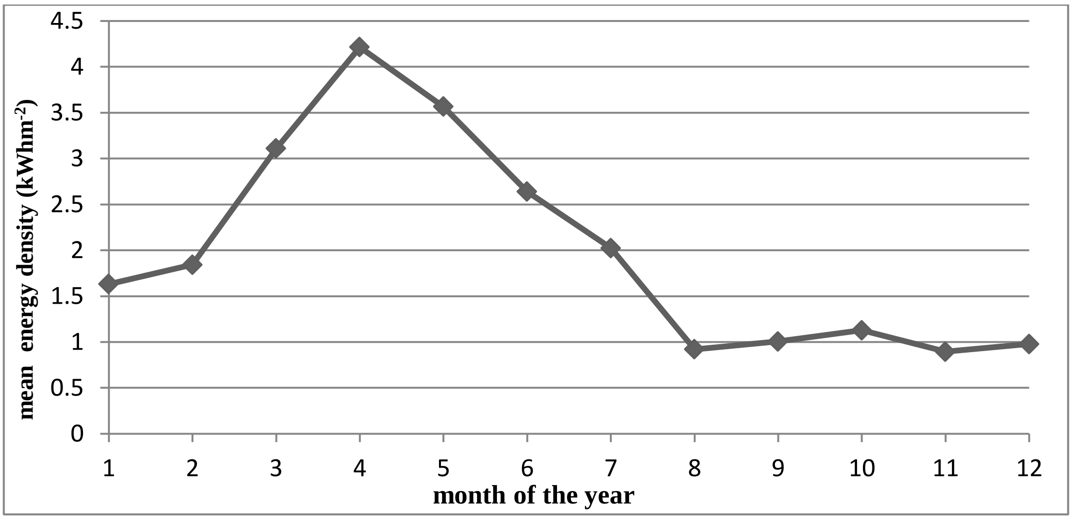

Figure 6: Variation of mean monthly energy density at the height of 30m

3.2 Weibull Probability Distribution and Duration Function

The probability density function for the wind mean velocity was given by

f(V_m)=(k/c)(〖V_m/c)〗^(k-1)*e^(-(V_m/c)^k) (12)

Accordingly the number of hours in a year with V_m>V_i was given as:

〖T(V〗_m)=8760*e^(-(V_m/c)^k) (13)

Where 8760hours is the number of hour per year. Using equations 12 and 13 table 3 was formed.

Table 3: Weibull probability distribution and duration function

V_m (ms-1)	$f(V_m)$	$T(V_m)$ (hr)
1.000	0.7002	5776.60
2.000	0.2714	764.70
3.000	$6.1306*10^{-03}$	0.8043
4.000	$1.9384*10^{-08}$	$5.0520*10^{-07}$

3.3 Discussion of Result

Table 1 shows the mean monthly wind speed, standard deviation, shape factor, scale factor, gamma function and power and energy densities of the area under study at 10m height and Table 2 shows the mean monthly speed, power and energy densities at 30m height after extrapolation. From figure 1 the speed range from $0.990ms^{-1}$ in November to $1.660ms^{-1}$ in April which is by far less than the $4.0ms^{-1}$ threshold speed required for electrical power generation. From figure 2 and 3 the power and energy densities at 10m ranges from 0.594Wm^{-2} to 2.802Wm^{-2} and 0.442kWhm^{-2} to 2.082kWhm^{-2} respectively and these densities were less than the minimum standards required. From figure 4 to 6, the values of speed, power densities and energy densities were found to range between 1.252ms^{-2} to 2.100ms^{-2}, 1.203Wm^{-2} to 5.672Wm^{-2} and 0.894kWhm^{-2} to 4.215kWhm^{-2} respectively and were less than the minimum standard required. Table 3 shows that the period of the year in which the mean speed of Yola is (1.000 and 2.000)ms^{-1} is (5776.600 and 765.700)hrs respectively. This translates to a probability of (0.700 and 0.271) respectively. Also the probability of obtaining mean speeds of (3.000 and 4.000)ms^{-1} are nearly zero.

IV. CONCLUSION

The study showed that the wind power potential assessment measured at 10m and 30m height of Yola the capital of Adamawa state in the north eastern part of Nigeria and the following conclusion were drawn:

1. Weibull's parameters (σ, k, c and Γ) were determined for the given speeds of the region under consideration and their average values were 0.543ms^{-1}, 2.537, 1.408ms^{-1} and 0.634 respectively.
2. The wind speeds of the region at 10m height were found to range from 0.990ms^{-1} in November to 1.660ms^{-1} in April and the average value is 1.253ms^{-1}.
3. The power and energy densities for the giving speeds at 10m height were found to range between 0.594Wm^{-2} to 2.802Wm^{-2} and 0.442kWhm^{-2} to 2.082kWhm^{-2} and their average values were 1.327Wm^{-2} and 0.986kWhm^{-2} respectively.
4. The wind speeds of the region at 30m height were found to range from 1.252ms^{-1} in November to 2.100ms^{-1} in April and the average value is 1.584ms^{-1}.
5. The power and energy densities for the giving speeds at 30m height were found to range between 1.203Wm^{-2} to 5.672Wm^{-2} and 0.894kWhm^{-2} to 4.215kWhm^{-2} and their average values were 2.687Wm^{-2} and 1.996kWhm^{-2} respectively.
6. The wind speeds, power densities and energy densities at 10m and 30m were by far less than the required values for electrical power generation.
7. These values may however be suitable for wind pumps especially in small rural communities needing small dispersed water supplies.

RECOMMENDATION

The extension of this study is desirable for a comprehensive mapping of the wind energy potentials of adamawa state and Nigeria as a whole.

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