Analysis of Wind Speed based on Weibull model and Solar Radiation Potential for Electricity Generation in Mubi, Nigeria

Nubwa U.M[1], Ogbaka D.T[2] and Julius J.K[3]

[1] *Federal Ministry of Labour and Employment, Plateau State, Nigeria*

[2]*Department of Pure and Applied Physics, Adamawa State University, Mubi, Adamawa State, Nigeria*

[3]*GGDSS Nassarawo/Jereng, Mayo-Belwa LGA Adamawa State Nigeria*

Abstract: **Development and advancement of any nation depend on the accessibility of reliable electric power energy. Global radiations obtained in this study are higher with mean value of 22.90 MJm^{-2} and the measured value 21.39 MJm^{-2} which shows the presence of high global solar energy potential in Mubi. The energy distribution density with August having the highest value of 30048.52 joules and January having the lowest value of 2010.07 joules, this is due to the average mean wind speed, the power distribution density with August having the highest value of 40.39W/m^2 and January having the lowest value 2.70W/m^2. The site has been found to have great potentials for wind and solar utility power generation capacity. The global solar radiation intensity predicted in this study can also be utilized in design, analysis and performance estimation of solar energy systems, which is gaining significant attention.**

Keywords: **Global Solar Radiation, Power Generation, Wind Energy, Weibull model.**

I. INTRODUCTION

Wind is one of the unlimited renewable energy resources which can provide with significant units of energy to bear the requirements of a nation. It is renowned that wind energy has stood out as the most precious and promising choice for generation of electricity. Earlier studies have proved that the installation of a number of wind turbine generators can effectively reduce environmental pollution, fossil fuel consumption, and the costs of overall electricity generation (Paritosh 2011).

The epileptic power supply throughout the nation has hindered the socio-economic growth and, subsequently, increase air pollution due to individual stand-alone diesel generators and hindered industrialization of the country. Various government incentives and policies have little or no effect to improve the availability and reliability of the electric power supply (Ahmed Mahammed, 2012).

For a country like Nigeria, the economical and efficient application of solar energy seems inevitable because of abundant sunshine available throughout the year. It has been found that there is an estimated 3,000 h of annual sunshine (Augustine and Nnabuchi, 2010) and average solar radiation received in Nigeria per day is as high as 20MJ/m^2 depending on the time of the year and location (Offiong, 2003). Despite this abundant availability of solar energy, Nigeria with over 97,000 rural communities, her population is characterized with deprivation from conventional energy, arising from poor supply of infrastructure. Where conventional energy is available, its supply is unreliable.

This is the major reason among many others prompted the emergence of study. This erratic nature of electric power supply has caused the economy to fall, unless it is supplemented. The way out of this lies in the use of renewable source of energy for power generation, as they contain enormous, largely untapped and sustained opportunity for meeting the energy need as they are environmentally friendly as they do not contribute harmful and toxic emission to it. The solar energy is one of the cleanest and most environmentally sources of energy capable of generating a high amount of electricity. The is based on the Analysis of Wind Speed based on Weibull model and Solar Radiation Potential for Electricity Generation in Mubi, Adamawa State.

II. METHODOLOGY

2.1 Study Area

The monthly mean daily data for sunshine hours were obtained from Department of Geography metrological unit situated in Adamawa State University, Mubi. The wind speed data was measured using a cup Anemometer at height of 10m and altitude of 579m. The wind speed data are statistically presented using both the monthly annual distribution and these distributions were obtained by evaluating five years arithmetic mean of the wind data across the months and years. The data obtained covered a period of five years (2009 – 2013) for Mubi, Nigeria located on latitude 10.2667° N and longitude 13.2667° E.

Among the existing correlations, the following relation is the generally accepted modified form of the Angstrom-type regression equation (Angstrom, 1924), relating the monthly average daily global radiation to the average daily sunshine hours.

$$\frac{H_m}{\bar{H}_o} = a + b\frac{S}{S_0} \qquad (1)$$

Where H_m is the monthly average global solar radiation ($MJm^{-2}day^{-1}$), S is the monthly average daily bright sunshine hour, S_0 is the maximum possible monthly average daily sunshine hour or the day length, a and b are coefficients of Angstrom's formula.

H_o, is the monthly average daily extraterrestrial radiation which can be expressed as:

$$H_o = \frac{24}{\pi} I_{sc} \left[1 + 0.033 \cos \frac{360n}{365}\right]\left[\cos \emptyset \cos \delta \sin \omega_s + \pi 180 \omega s \sin \emptyset \sin \delta\right. \quad (2)$$

Where n is the Julian day number, I_{sc} = 1367Wm^{-2} is the solar constant, $\emptyset$ is the latitude of the location, δ is the declination angle given as:

$$\delta = 23.45 \sin\left(360 \frac{284+n}{365}\right) \quad (3)$$

And ω is the sunset hour angle as

$$\omega = \cos^{-1}(-\tan\emptyset \tan\delta) \quad (4)$$

The maximum possible sunshine duration $\bar{S}_0$ is given by

$$S_0 = \left(\frac{2}{15}\right) \omega \quad (5)$$

According to Neuwirth (1980), regression coefficient *a* and *b* from the calculated monthly average global solar radiation has been obtained from the relationship given as:

$$a = -0.110 + 0.235 \cos \emptyset + 0.323 \left(\frac{S}{S_0}\right) \quad (6)$$

$$b = 1.449 - 0.553 \cos \emptyset - 0.694 \left(\frac{S}{S_0}\right) \quad (7)$$

compute estimated values of the monthly average daily global radiation H_m, the values of computed a and b from equations (6) and (7) were used in Equation (1).

2.2 Mean Wind Speed

Mean wind speed (MWS) is the most commonly used indicator of wind production potential, the mean speed is defined as

$$Vm = \frac{1}{N} \sum_{i=1}^{N} Vi \quad (8)$$

Where N is the sample size and $V_{i\,l}$ is speed recorded for end observations.

2.2 Monthly Average Wind Speed and Standard Deviation

The monthly average wind speed (V_m) and the standard deviation (σ) were obtained using equations 1 and 2

$$\sigma = \left[\frac{1}{N-1} \sum_{i-1}^{N} (Vi - Vm)^2\right]^{1/2} \quad (9)$$

Where, N is the number of years considered, Vi is the wind speed value of each month ms^{-1}, V is the mean wind speed ms^{-1}, σ is the standard deviation

2.3 Weibull Distribution

The Weibull distribution (F_w) is:

$$f_{w(vj)} = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)k\right] \quad (10)$$

There are several methods presented in the literature to identify the perimeters of the weibull function, such as the scale factor (C) and the shape factor (K). However, for this study the following equations were used to evaluate (C) and (K).

$$C = V_m \left[\frac{K2.6674}{0.184 + (0.816k)^{2.6674}}\right] \quad (11)$$

$$K = \left(\frac{\sigma}{Vm}\right)^{-1.090} \quad (12)$$

2.4 Power and Energy Density Distributions

The power in the wind is equal to the energy per unit time. The energy available is the kinetic energy of the wind. The power density ($P_{(v)}$) and energy density ($E_{(V)}$) of the wind, which are the energy of the wind per unit area.

$$E(v) = \frac{1}{2} \ell V_m^3 t \quad (12)$$

Where, t is the number of hours in a month, ℓ is the density of air and assumed to be 1.225kg/m3 in the study (Rai, 2004) and (Rao and Parulekar, 2004)

$$P(v) = \frac{1}{2} \ell V_m^3 \quad (13)$$

III. RESULTS AND DISCUSSION

Table 1: Metrological data and Global Solar Radiation for Mubi

Month	$\bar{S}$ (hr)	$\bar{S}_o$ (hr)	$\bar{S}/\bar{S}_o$	H_m	H_o	$\frac{H_m}{H_o}$	$\frac{H_e}{H_o}$
Jan	6.26	12.55	0.58	21.42	39.41	0.54	0.53
Feb	5.92	7.01	0.84	22.32	27.95	0.79	0.76
Mar	7.61	13.56	0.64	23.89	39.70	0.60	0.65
Apr	5.48	12.54	0.53	22.39	33.67	0.66	0.56
May	6.18	12.55	0.57	21.20	39.28	0.53	0.59
Jun	5.42	12.54	0.43	19.62	33.87	0.57	0.47
Jul	5.12	12.55	0.42	19.05	39.14	0.48	0.47
Aug	5.22	12.55	0.40	17.67	37.71	0.46	0.45
Sep	5.62	12.54	0.45	18.67	33.81	0.55	0.52
Oct	5.81	12.55	0.46	19.39	39.54	0.49	0.52
Nov	5.75	12.54	0.45	19.47	33.76	0.57	0.54
Dec	4.97	12.55	0.48	19.60	39.34	0.49	0.48

Table 2: Monthly mean average of regression constants, extraterrestrial solar radiation, measured and calculated values, measured and calculated clearness index for Mubi.

Month	a	b	H_m	H_o	H_e
Jan	0.27	0.54	21.42	39.41	21.06
Feb	0.40	0.43	22.32	27.95	21.27
Mar	0.30	0.56	23.89	39.70	26.13
Apr	0.25	0.60	22.39	33.67	19.12
May	0.28	0.55	21.20	39.28	23.31
Jun	0.25	0.53	19.62	33.87	16.18
Jul	0.25	0.54	19.05	39.14	18.66
Aug	0.25	0.52	17.67	37.71	17.27
Sep	0.26	0.52	18.67	33.81	17.60
Oct	0.27	0.55	19.39	39.54	20.67
Nov	0.27	0.56	19.47	33.76	18.52
Dec	0.23	0.53	19.60	39.34	19.05

Table 3, 4, 5 and 6 shows the monthly means of wind speed , mean wind speed and standard deviation, Weibull distribution, Energy and power distribution Density.

Table 3: Mean wind Speed and standard deviation

Months	Vi (ms^{-1})	Vm (ms^{-1})	σ	K	C(ms^{-1})
Jan.	4.92	1.64	2.32	0.685	1.24
Feb.	7.73	2.58	3.64	0.685	1.95
Mar.	6.14	2.05	2.89	0.687	1.56
April	7.43	2.48	3.50	0.688	1.87
May	7.61	2.54	3.59	0.687	1.93
Jun	8.00	2.67	3.77	0.687	2.03
Jul	5.97	1.99	2.81	0.687	1.51
Aug.	12.11	4.04	5.71	0.686	3.06
Sept.	10.22	3.41	4.82	0.686	2.59
Octo.	6.13	2.04	2.89	0.684	1.54
Nov.	6.08	2.03	2.86	0.688	1.54
Dec.	6.20	2.07	2.92	0.687	1.57

Table 4: Shows the Weibull Distribution

Months	F_w	Vi (ms^{-1})	K	C(ms^{-1})
Jan.	0.024	4.92	0.685	1.24
Feb.	0.015	7.73	0.685	1.95
Mar.	0.019	6.14	0.687	1.56
April	0.016	7.43	0.688	1.87
May	0.015	7.61	0.687	1.93
Jun	0.0047	24.86	0.686	6.29
Jul	0.019	5.97	0.687	1.51
Aug.	0.0097	12.11	0.686	3.06
Sept.	0.011	10.22	0.686	2.59
Octo.	0.019	6.13	0.684	1.54
Nov.	0.019	6.08	0.688	1.54
Dec.	0.019	6.20	0.687	1.57

Table 5: Shows the Energy and Power Distribution Density

Months	$E_{(v)}$ (joule)	$P_{(v)}$ (w/m^2)
Jan.	2010.07	2.70
Feb.	7068.62	10.52
Mar.	3925.91	5.28
April	6726.57	9.34
May	7467.56	10.04
Jun	8394.07	11.66
Jul	3591.19	4.83
Aug.	30048.52	40.39

Sept.	17486.45	24.29
Octo.	3868.74	5.20
Nov.	3689.15	5.12
Dec.	4041.94	5.43

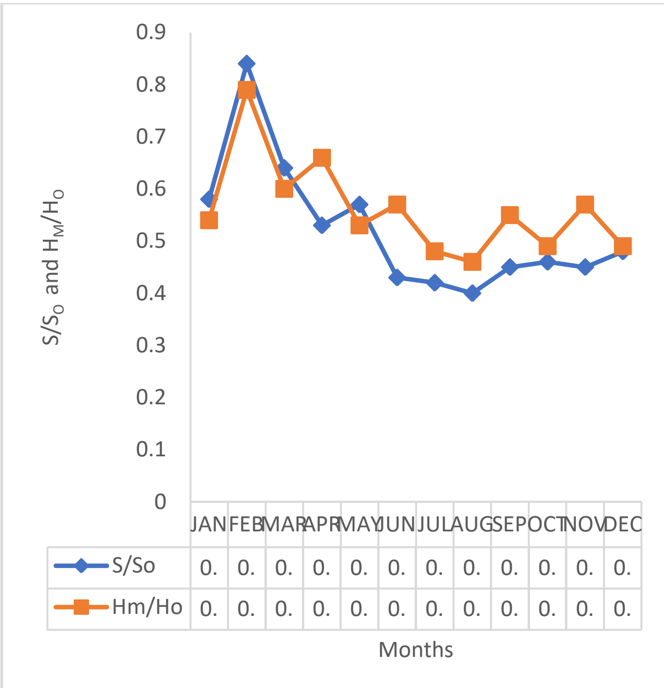

Figure 1: Variation of S/S_o and H_m/H_o (The clearness index) for Mubi

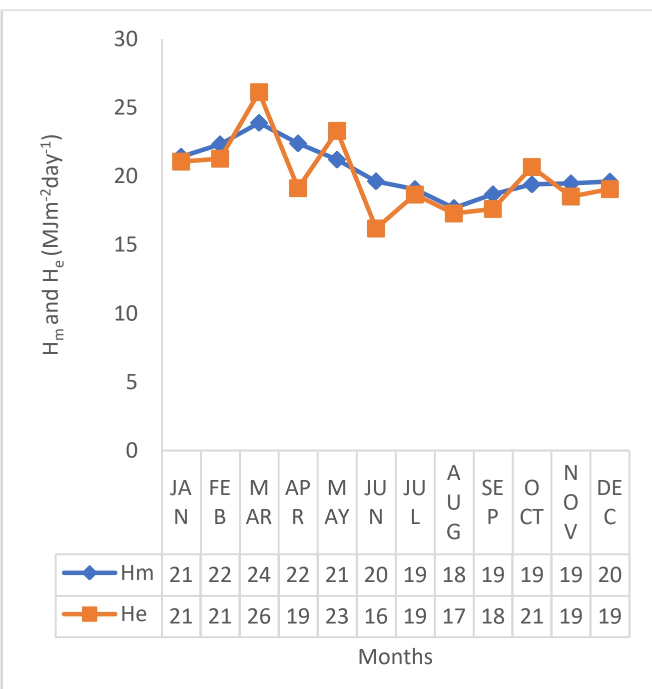

Fig. 2: Comparison between measured and predicted Solar Radiation

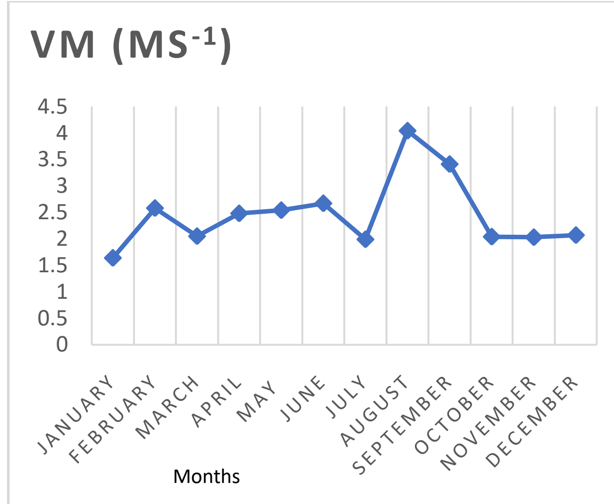

Fig. 3: Monthly average mean wind speed.

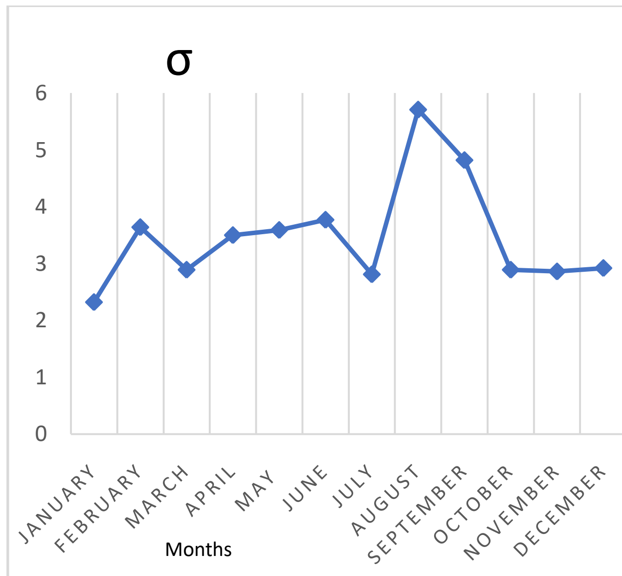

Fig. 4: Represent the standard deviation of the mean wind speed.

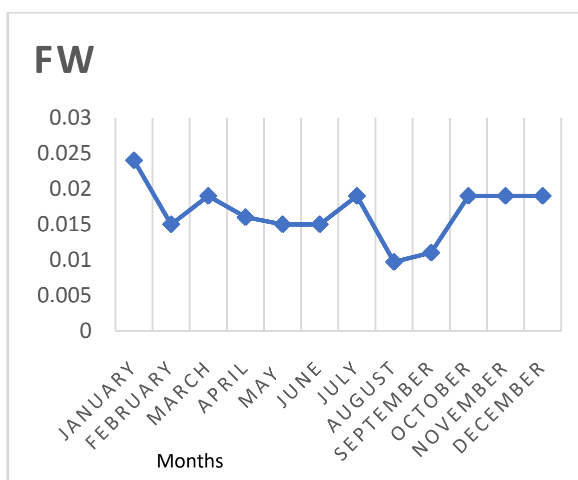

Fig. 5: Represent the Weibull Distribution function.

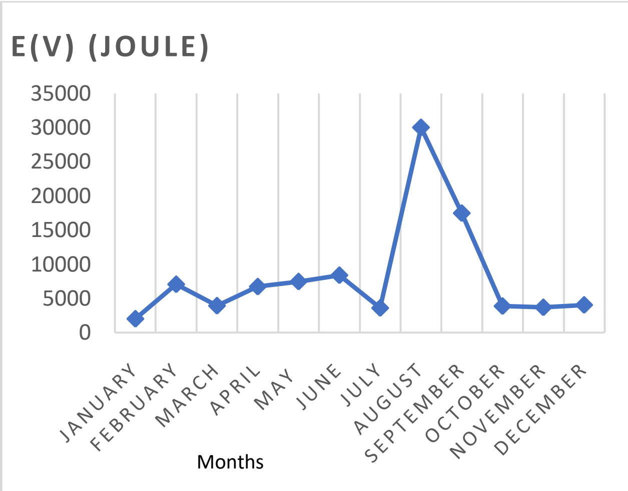

Fig. 6: Represents the Energy distribution density.

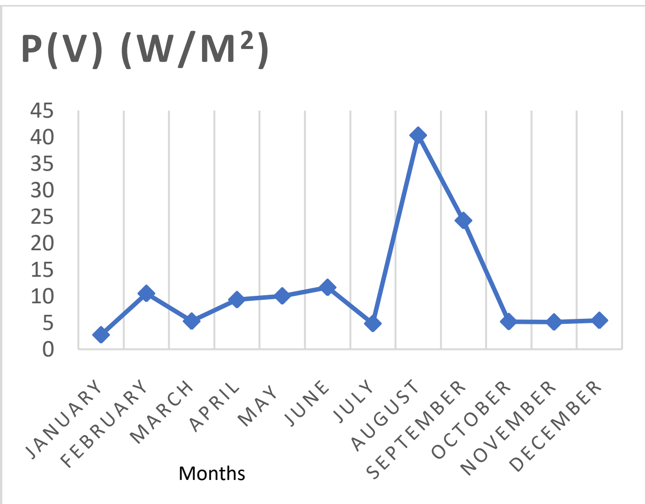

Fig. 7: Represents the Power distribution density.

The extraterrestrial solar radiation H_o ($MJm^{-2}day^{-1}$) and the monthly day length S_o (hr) were computed for each month using equations (2) - (5), the input parameters for the calculation of the mean monthly global solar radiation for Mubi are shown in the Table 1 and 2. Using these parameters, the regression constants 'a' and 'b' evaluated as 0.27 and 0.54 respectively. Substituting these values into equation (1), we now established the empirical correlation for the estimation developed for Mubi as:

$$\frac{H_m}{H_o} = 0.27 + 0.54\left(\frac{S}{S_o}\right) \quad (14)$$

The value of H_e/H_o (= 0.45) corresponding to the lowest value of S/S_o (= 0.40) and H_e ($17.27MJm^{-2}day^{-1}$) in the month of August is an indication of poor sky condition. These conditions correspond to the general wet or rainy season (June - September) observed in Nigeria, during which there is much cloud cover.

The regression constants (Table 3), a and b of different months were evaluated from equations (7) - (8). To compute the calculated values of the mean monthly average of global solar radiation H_e, the values of a and b were inserted into equation (1) and the correlation may be used to compute H_e at other locations having the same altitude. Looking at these values of measured and calculated clearness indexes; it is observed that both of them had the lowest values in the month of August. (Throughout the year) H_m/H_o (= 0.46), H_e/H_o (= 0.45) with H_m ($17.67MJm^{-2}day^{-1}$) and H_e (= 17.27 $MJm^{-2}day^{-1}$) which can be traced to the meteorological conditions for Mubi.

As it can be seen in table 3, fig 3 the monthly average mean wind speed is lower with the value of 1.64 m/s, in the month of January average mean wind speed is higher in the month of august with the value of 4.04 m/s.

Shown in table 3, the Weibull distribution test result was gotten from equations 12 - 15 such that the scale factor (C) and the shape factor (K) was used in order to determine the Weibull distribution function of Mubi for the past three years, which shows that the month of August has the lowest value (0.0097) and in the month of January it is at its highest peak at (0.024).

Table 5 and fig 6 shows the energy distribution density with August having the highest value of 30048.52 joules and January having the lowest value of 2010.07 joules, this is due to the average mean wind speed as shown in table 4. and fig 3. Table 5 and fig 7 shows the power distribution density with August having the highest value of 40.39W/m^2 and January having the lowest value 2.70W/m^2

This provides favorable condition for solar energy. Global radiations obtained in this study are higher with mean value of 22.90 MJm^{-2} and the measured value 21.39 MJm^{-2} which shows the presence of high global solar energy potential in Mubi, Nigeria. According to Offiong, (2003) reports that an average solar radiation for Nigeria per month needs to be as high as 20 MJm^{-2} depending on the time of the year which required for which is within the threshold for which Photovoltaic cell can be used to generate electricity.

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