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Assessment of Wind and Solar Energy Potential at ADUSTECH-Wudil for Hybrid Electricity Generation Using Weibull Distribution and Samani Model

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ABSTRACT

Intermittent nature of electricity supply in Nigeria is not only affecting social-economic sector, also educational sector. It affects activities such as lecture presentation, laboratory practical etc. Also, the inconsistency in the cost of fuel is making it difficult to conduct some laboratory practical in some Nigerian Universities. This work analyzed the wind and solar data of Aliko Dangote University of Science and Technology (ADUSTECH), Wudil (formerly known as Kano University of Science and Technology, Wudil (KUST-Wudil)), to assess their potentials in complementing the electricity supply from National grid. The methods employed are Weibull probability distribution and Samani Model for wind and solar assessment, respectively. Data from Nigerian Meteorological Agency (NIMET) for three years (2018 to 2020) is used in the study. The wind power density obtained based on Weibull distribution parameters is 308.06 W/m^2 in March and 465.94 W/m^2 in November, with minimal error of 0.09 on a scale of RMSE. In the Samani model it is observed that an estimated solar radiation of about 10.5 MJ/m^2/day in March and about 27 MJ/m^2/day in July. According to National Renewable Energy Laboratory (NREL) the site is above class 3 for wind power generation, thus recommended for hybrid system to complement the supply from national grid and to complement each other.

1. INTRODUCTION

The intermittency of electricity supply in Nigeria is heating development of lot of sectors, including education sector. This makes it necessary to introduce renewable energy resources, to complement the meager electricity supply from national grid. Aliko Dangote University of Science and Technology (ADUSTECH), Wudil in particular is suffering from the same problem, which may lead to skipping of student practical/experiments. To curtail this issue there is need for providing alternative electricity supply as a back-up, so that in the absence of supply from the national grid the renewable energy supply can take over.

On the other hand, the variation of wind speed and lack of energy storage facility in the area requires investigation on the available renewable energy resources. This is only possible through comparison on the potentials of the available renewable energy resources (wind and solar). This would give a reliable information on which among the two sources can give the needed electricity supply.

Research works were conducted and implemented in different locations and the results have aided in choosing the most reliable source of renewable energy for such locations. Among the recent ones is [1], in which wind, solar, biogas and battery were hybridized to complement main grid supply. The system is successful in operation thereby eliminating power outages. In [2] wind and solar were integrated with main grid for optimal energy dispatch and locational marginal market price. A renewable energy resources system incorporation with storage system is implemented in [3] to serve as distributed generation to the system. Some researchers, such as [4], [5] [6] and [7] predicted the availability of the wind energy for future usage. Their work showed significant result and recommends for the use of Artificial Intelligence approaches in solar energy prediction. Despite the research works presented in the literature, there is little concern on application of renewable energy resources in academic activities, and no study on the feasibility studies of the resources in ADUSTECH-WUDIL, in particular.

The main purpose of this research is to investigate the feasibility of assessing RES potentials of Wudil town, in West-eastern region of Kano state for development of either wind power generation (using wind turbine) or solar power generation (using solar Photovoltaic (PV)). It will employ statistical methods to find a suitable renewable energy resource that can serve the electronics laboratory in the faculty of Engineering of the University.

2. STUDY AREA AND DATA USED

Study Area: Wudil is located in the south-eastern part of Kano State. As a nodal town it is situated around river Wudil, which enhances the flow of wind and may possibly provide the needed wind energy. The town is located between latitude 11N and 8.2127 N and longitude 8 E and 5 E of the Greenwich meridian with land mass of about 459km^2, it is surrounded by Gaya local government to the east, Warawa local government to the West and North and Garko and Albasu local government to the South [8].

Data Collection: Data comprised of daily solar irradiance, wind speed and temperature, obtained from Nigerian Meteorological Agency (NIMET) for a period of three years (2018 to 2020) is used. The data undergone cleaning to remove outliers.

3. WIND ENERGY POTENTIAL ASSESSMENT OF WUDIL

As reported in [9], wind energy potential can be assessed using Weibull distribution function [10] in which wind speed is the required parameter to determine average wind speed and standard deviation. This method has been applied and produce good results in many research works, such as [9][11][12] and [13]. The model is proved to be effective even in uncertain environment [14].

3.1 Average wind speed and standard deviation

To evaluate the wind potential of Wudil, there is need to determine the average wind speed and standard deviation of the wind recorded over time. As mentioned earlier, wind speed is used to calculate the monthly average wind speed (V_m) and standard deviation (σ), considering equations (1) and (2) [10].

$$V_m = \frac{1}{N}\left(\sum_{i=1}^{N} V_i\right) \tag{1}$$

$$\sigma = \left[\frac{1}{N-1}\sum_{i=1}^{M}(V_i - V_m)^2\right]^{1/2} \tag{2}$$

where V_m is the average wind speed in m/s; σ is the standard deviation of the observed data in m/s; V_i is the monthly wind speed in m/s for month i; N is the number of wind speed data in a particular month.

3.2 Weibull parameters

Weibull distribution function [15] is a statistical algorithm used to describe wind speed variation in the study area. Two parameters of interest are shape parameter, k and scale parameter, c, which are used to determine the probability density function [16] of the wind speed, as shown in equation (3).

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{3}$$

where v is the average wind speed, with help of the variance of the wind speed the shape and scale parameters can be obtained using equations (4) and (5)

$$k = \left(\frac{\sigma}{v}\right)^{-1.086} \text{ for } (1 \le k \le 10), \tag{4}$$

$$\text{and } c = \frac{v}{\Gamma\left(1+\frac{1}{k}\right)}\frac{m}{s} \tag{5}$$

From the above relations, the average speed V_a is given by [6]

$$v_a = c\Gamma\left(1+\frac{1}{k}\right)\frac{m}{s}.$$

Note that the gamma function can be expressed as

$$\Gamma(x) = \int_0^\infty t^{x-1}\exp(-t)dt \quad (6)$$

The performance of the Weibull distribution function can be evaluated using Root Means Square Error (RMSE), as expressed in equation (7). The variation in accuracy of the Weibull methods is obtained by comparison with data obtained from the study area via NIM ET.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(y_i - x_i\right)^2} \quad (7)$$

Where y_i is the i^{th} wind speed data and x_i is the corresponding Weibull computed data.

3.3 Determination of vertical height of the wind speed

Value of wind speed depends on the vertical hight, the higher the head the faster the speed. Therefore, determination of the estimated wind turbine hight that can give the required wind speed is necessary. Therefore, from equation (8) [11]

$$v_2 = \left(\frac{h_2}{h_1}\right)^{\alpha} v_1 \quad (8)$$

where v_1 is the corresponding speed at height, h_1 and v_2 is estimated wind speed using extrapolation at particular head, h_2. The surface roughness coefficient, α is given by [17]

$$\alpha = \frac{\left[0.37 - 0.088\ln[v_1]\right]}{1 - 0.088\ln\left[\frac{h_1}{10}\right]}$$

This parameter depends on the season of the year, time of the day and height at which the speed is measured. In some literature it is referred as wind shear factor.

3.4 Estimation of wind power density

The mean wind speed is used to determine the wind power (in Watt) available at the research area. It is calculated by considering the size of the wind turbine blade. Using equation (7) [15], the wind power density is given by

$$P_w(v) = \frac{1}{2}\rho A V_m^3 \quad (9)$$

where ρ is the standard air density (a function of altitude, air pressure and temperature) selected as 1.225kg/m^3 as recommended in [9], A is the swept area in m^2. According to Weibull probability density function, the wind power density can be determined using the following relation [7].

$$P(v) = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) \quad (10)$$

4. SOLAR ENERGY ASSESSMENT OF WUDIL

Pokhrel *et al* [18] reported that it is necessary to estimate solar energy in the proposed installation area before engaging into the project. The commonly used methods in estimating solar energy availability are empirical and soft computing techniques [19]. The model presented in this work is based on the air temperature. The important parameters required for assessing the solar energy are:

i. Air temperature amplitude
ii. Extra-terrestrial solar radiation
iii. Declamation angle
iv. Solar hour angle
v. Latitude and
vi. Day of the year

4.1 Extra-terrestrial global solar radiation

The average extra-terrestrial global solar radiation per day is calculated using equation (11) [9]

$$H_0 = \frac{24}{\pi} I_{SC}(A)\times(B) \quad (11)$$

Where $A=\left(1+0.033\cos\left(\frac{360N}{365}\right)\right)$ and

$$B=\left(\cos\phi\cos\delta\sin\omega+\frac{2\pi}{360}\sin\delta\sin\phi\right)$$

and I_{sc} is the solar constant given as 1.367kW/m^2 ; ϕ is the latitude of the location in degrees; δ is the solar declination angle in degrees; ω is the sunset hour angle also in degrees, and N is day of the year, starting with 1 for January 1st and 365 for December 31st. The solar declination angle can be determined from equation (12) [20].

$$\delta=-23.45\times\cos\left[\frac{360}{365}(N+10)\right] \tag{12}$$

The day angle (in radians) is given by

$$\alpha=\frac{2\pi\times(N-1)}{365} \tag{13}$$

The sunset hour's angle is given by equation (11)

$$\omega=\cos^{-1}\left[-\tan\delta\tan\phi\right] \tag{14}$$

The temperature amplitude, K_T is determined using equation (15)

$$K_T=\frac{H_C}{H_0} \tag{15}$$

$$\Rightarrow H_C=K_T\times H_0$$

In which H_C is the average horizontal surface radiation and H_0 is the extra-terrestrial radiation of the atmosphere.

4.2 Samani air temperature amplitude based model

Samani [21] has further improved the empirical coefficient K_T in equation (15). With aim of reducing the error in the estimated global solar radiation in one year average monthly data. Thus

$$K_T=A\left(T_{\max}-T_{\min}\right)^2+B\left(T_{\max}-T_{\min}\right)+C \tag{16}$$

The model for the extra-terrestrial radiation is given in equation (17)

$$H_C=H_o\left[\left(A\left(T_{\max}-T_{\min}\right)^2+B\left(T_{\max}-T_{\min}\right)+c\right)\left(T_{\max}-T_{\min}\right)^{1/2}\right] \tag{17}$$

Where the coefficients A, B and C are computed by Samani based on 65 American whether stations, according to [20]. The computed values as adopted by [9, 20] are A = 0.00185 ºC^{-2}, B = -0.04330 ºC^{-1} while C = 0.40230.

5. RESULTS AND DISCUSSIONS

5.1 Yearly average wind speed

It can be observed in figure 1 that the average wind is not constant over the three years, 2018 and 2019 show a little fluctuations in the monthly wind speed whereas the variation in 2020 is higher, for example November presents the highest wind speed of about 10.11 m/s and lowest wind speed is in April with a value of 6.35 m/s. In 2018 the highest and lowest wind speeds are 8.9 m/s and 7.4 m/s respectively, and in 2019 the highest and lowest are 8.5 m/s and 7.6 m/s respectively. This shows that if the pattern continues as shown in the figure the wind speed will be increasing every year.

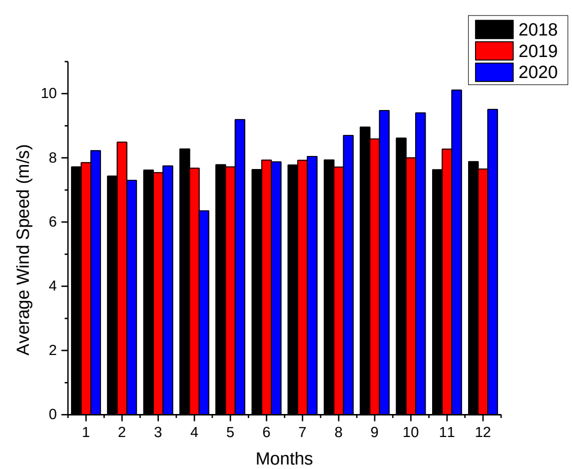

Figure 1: Average wind speed of Wudil for the three years under investigation

5.2 Variation in average wind speed

Generally, the average wind speed variation over the three years is not encouraging. As presented in figure 2, the average recorded wind speed over the three years is in September, April recorded the lowest average. This corresponds to what is obtainable in Table 1, in which the lowest average power density is in March and highest is in September. Therefore, the study area can produce a minimum of 308.04 W/m^2 average wind power density. Even with this lower power density, the site is good for the mentioned purpose, because the laboratory has low power consumption equipment. This model has shown a significant results with average RMSE of 0.09.

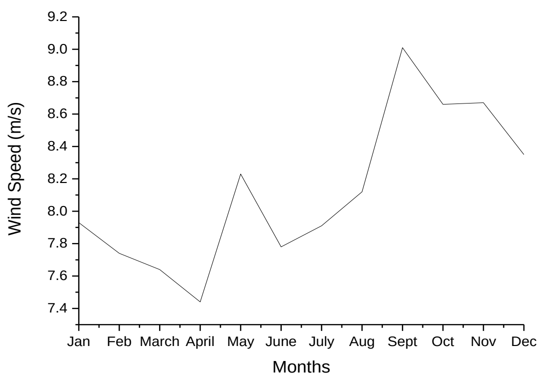

Figure 2: Yearly wind speed variation of Wudil

Table 1: Average wind power density of Wudil

Months	V_m (m/s)	c (m/s)	k	P (w/m^2)	RMSE
Jan	7.36	8.08	3.76	345.04	0.07
Feb	6.08	7.95	3.69	325.57	0.07
March	7.09	7.85	3.63	308.29	0.07
April	6.90	7.66	3.61	338.80	0.07
May	7.64	8.41	3.95	419.35	0.08
June	6.07	8.01	3.73	350.56	0.07
July	7.35	8.11	3.78	353.95	0.07
Aug	7.54	8.31	3.88	385.48	0.07
Sept	8.36	9.15	4.38	633.59	0.09
Oct	8.05	8.84	4.18	465.78	0.08
Nov	8.05	8.84	4.17	465.94	0.08
Dec	7.75	8.53	4.00	409.12	0.28
Average	**7.35**	**8.31**	**3.90**	**400.12**	**0.09**

5.3 Weibull performance parameters

Figure 3 shows the Weibull distribution curve. The Weibull parameters used in developing the function are shown in Table 1. The data used in this work is recorded over the height of 17m. This height is too much for the study area, and considering the application of the work, the power needed may not be that much. Thus, equation (8) is used to extrapolate the wind speed value over the height of 10m. Therefore, these parameters are calculated based on proposed 10m height of the wind turbine.

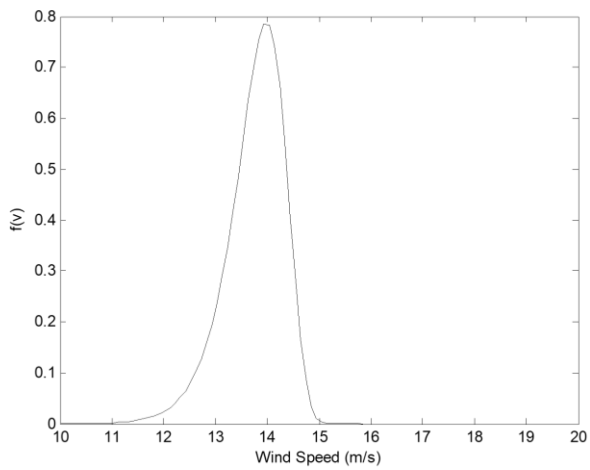

Figure3: Weibull probability density function

A shown in Table 1, the Weibull scale parameter has a range of 7.66 m/s to 8.84 m/s, and the shape parameter ranges from 3.61 to 4.38. Both the scale and shape parameters recorded a lower value in April and higher value in September. This corresponds to the lowest wind speed in April and highest in September, and so also the wind power density. The Weibull cumulative probability distribution is shown in Figure 4. It can be observed that the probability distribution function and the cumulative distribution are within a good fit of 10m/s to 16 m/s.

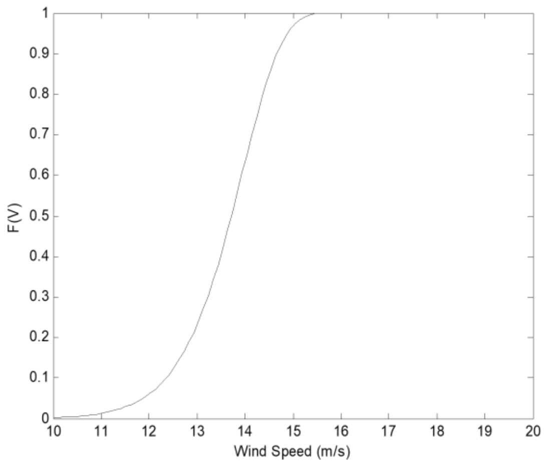

Figure 4: Weibull cumulative probability distribution for wind speed

5.4 Wind power density and different heights

Figure 5 presents the wind power density at the measured height and proposed height. It is clearly observed that at 17m height the power is high, just like the wind speed, the study purpose is to supply electronic devices. Similarly the height of 17m is too long, thus make it necessary to extrapolate the height to 10m. As recommended by National Renewable Energy Laboratory (NREL), the study area (Wudil) is within a value above class 3 for wind power generation.

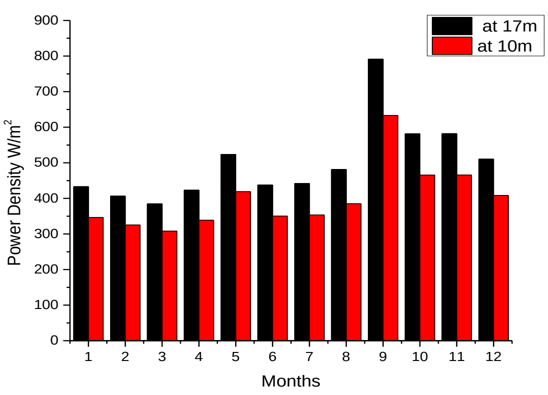

Figure 5: Wind power density at 17m and 10m heights

5.5 Temperature amplitude and estimated solar radiation

Unlike the wind speed, there is no much variation in the monthly temperature. This is similar for both minimum and maximum temperatures.

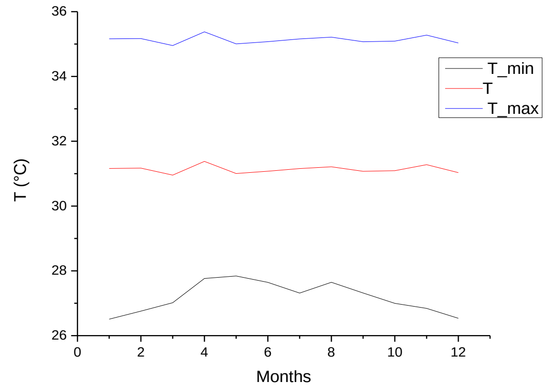

Figure 6: Average Temperature, Minimum Temperature and Maximum Temperature over the three years

From figure 6, the T_min is the minimum temperature, T_max is the maximum temperature and T is the mean temperature. The highest temperature in the all three categories occurs around April, this is due to hot season and dry air. The lowest temperature is from August to December. This is due to rainy season around the months of August to October. The temperatures is lower from November up to February due to winter season.

The estimated average global solar radiation is depicted in figure 7. January and July has the highest radiation, followed by May, June and then November. But the lowest occurs in March. This is the month with lowest power density as presented in Table 1. Base on these characteristics the investigation shows that the site is good for both solar and wind power generation, thus a hybrid system can suite the power supply of the area so that wind can complement solar in the night and vice-versa.

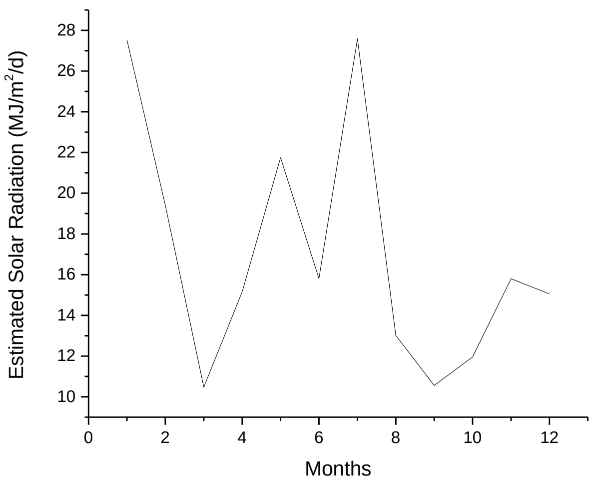

Figure 7: Estimated global solar radiation

6. CONCLUSION

This work assessed Wudil metrological data to investigate the potentials of wind and solar as sources of renewable energy. Data form NIMET is collected for three years, 2018 to 2020 and analysed using Weibull distribution and Samani model. In all the three years 2020 has the highest fluctuations in wind speed with November has the highest and April has the lowest, but the average wind speed over the three years shows that September has the highest. The wind power density as observed based on the Weibull distributions is encouraging. The lowest recorded value is 308.06W/m^2 in March and the highest is from September to December. The accuracy if the model based on the available data produces an RMSE of 0.09.

On the other hand, the highest temperature occurs in April due to hot season and dry air, and lowest from August to December due to rainy season around the months of August to October. The temperatures is lower from November up to February due to Harmatan season. The average global solar radiation as estimated using Samani model shows the highest in January and July, followed by May, June and then November, but lowest in March. This is corresponds with the month that has lowest power density. Base on these characteristics and according to National Renewable Energy Laboratory, the site is good for both solar and wind power generation, thus a hybrid system is recommended in the area so that wind can complement solar in the night and vice-versa.

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REFERENCES

1. Zaheeruddin, Manas M (2015) Renewable energy management through microgrid central controller design: An approach to integrate solar, wind and biomass with battery. Energy Reports 1:156–163. doi: 10.1016/j.egyr.2015.06.003

2. Samakpong T, Ongsakul W, Polprasert J (2014) Robust Optimization-Based AC Optimal Power Flow Considering Wind and Solar Power Uncertainty. 19–21.

3. Fu Q (2013) Modeling , Analyses and Assessment of Microgrids Considering High Renewable Energy Penetration.

4. Salisu S, Mustafa MW, Mustapha M, Otuoze AO (2019) A Hybrid PSO-ANFIS Approach for Horizontal Solar Radiation Prediction in Nigeria. ELEKTRIKA Journal of Electrical Enginrring 18:23–32.

5. Salisu S, Mustafa MW, Mustapha M (2018) A Wavelet Based Solar Radiation Prediction in Nigeria Using Adaptive Neuro-Fuzzy Approach. Indonesian Journal of Electrical Engineering and Computer Science 12:907–915. doi: 10.11591/ijeecs.v12.i3.pp907-915

6. Gupta RA, Kumar R, Bansal AK (2015) BBO-based small autonomous hybrid power system optimization incorporating wind speed and solar radiation forecasting. Renewable and Sustainable Energy Reviews 41:1366–1375. doi: 10.1016/j.rser.2014.09.017

7. Golestaneh F, Pinson P, Gooi HB (2016) Very Short-Term Nonparametric Probabilistic Forecasting of Renewable Energy Generation With Application to Solar Energy. Power Systems, IEEE Transactions on PP:1–14. doi: 10.1109/TPWRS.2015.2502423

8. Dambazau AM (2016) A Summary of the Geography of Wudil Local Government Area.

In: Olofin EA, Nabegu AB, Dambazau AM (eds) Wudil within Kano Region: A Geographical Synthesis. Ahmadu Bello University Press Limited, Zaria, Kaduna State, pp 149–177

9. Mudasiru M, Mustafa MW (2018) Wind and Solar Radiation Potential Assessment in Kano , Nigeria Using Weibull and Samani Models. ELEKTRIKA 17:21–27.

10. Justus CG, Hargraves WR, Mikhail A, Graber D (1978) Methods for Estimating Wind Speed Frequency Distributions. Journal of Applied Meteorology 17:350–353.

11. Akpinar EK, Akpinar S (2004) Statistical analysis of wind energy potential on the basis of the Weibull and Rayleigh distributions for Agin-Elazig , Turkey. Journal of Power and Energy 218:557–565.

12. Anwar Khan P (2014) Wind Energy Potential Estimation for Different Regions of Bangladesh. International Journal of Renewable and Sustainable Energy 3:47. doi: 10.11648/j.ijrse.20140303.11

13. Aljeddani SMA, Mohammed MA (2023) A novel approach to Weibull distribution for the assessment of wind energy speed. Alexandria Engineering Journal 78:56–64. doi: 10.1016/j.aej.2023.07.027

14. Albassam M, Ahsan-ul-haq M, Aslam M (2023) Weibull distribution under indeterminacy with applications. AIMS Mathematics 8:10745–10757. doi: 10.3934/math.2023545

15. Masters GM (2013) Renewable and Efficient Electric Power Systems. John Wiley & Sons, New Jersey

16. Ohunakin OS (2011) Wind Characteristics and Wind Energy Potential Assessment in Uyo , Nigeria. Journal of Engineering and Applied Science 6:141–146. doi: 10.3923/jeasci.2011.141.146

17. Oyedepo SO, Adaramola MS, Paul SS (2012) Analysis of wind speed data and wind energy potential in three selected locations in south-east Nigeria. International Journal of Energy and Environmental Engineering 3:1–11.

18. Pokhrel AK, Adhikari HP, Joshi U, et al. (2023) Prediction of Solar Radiation using Empirical Models over Lowland Region Nepal. Nepal Physical Society 9:51–57.

19. Gupta S, Singh AK, Mishra S, et al. (2023) Estimation of Solar Radiation with Consideration of Terrestrial Losses at a Selected Location — A Review. Sustainability 15:1–29.

20. Almorox J, Bocco M, Willington E (2013) Estimation of daily global solar radiation from measured temperatures at Cañada de Luque , Córdoba , Argentina. Renewable Energy 60:382–387. doi: 10.1016/j.renene.2013.05.033

21. Samani Z (2001) Estimating Solar Radiation and Vapotranspiration Using. Journal of Irrigation and Drainage Engineering 126:265–267.