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# Wind Energy Resource Assessment in Nigeria: A Methodological Approach

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**ABSTRACT**

The need to include wind power in the renewable energy resources development in Nigeria is identified, and a general method of evaluation of the wind energy potential of any location is presented. The method is illustrated using routine meteorological data collected at Benin City between 2010 and 2021 data. It is shown that the assessment of the wind energy potential of any location would require a detailed analysis of the hourly daily and monthly values of the velocity over several years. This is with a view to determining certain statistical characteristics of the wind velocity distribution, such as the variance, relative frequency and cumulative frequency.

## INTRODUCTION

Recent efforts on the development of the renewable energy resources in Nigeria have concentrated on the thermal applications of direct solar radiation, while other renewable energy resources have virtually been neglected. One of such renewable energy resources is wind energy. This refers to the kinetic energy of moving atmospheric air, which arises due to the differences over large area in the balance of radiation between various geographical latitudes on the one hand, and between the land and sea masses on the other. These produce overall differences in pressure which give rise to wind.

Thus, wind is derived directly from solar energy, about 1.5% to 2.5% of the latter being converted to wind on a global basis. This implies that for Nigeria with an average annual isolation on the ground of over 100 GJ/m$^2$ per year, about 1.5 to 2.5 GJ/m$^2$ per year of wind energy could be expected (Ezekwe and Ezeilo, 1981).

With an area of about 0.913 million square kilometers, it follows that the country's wind energy resource availability is over $1.4\text{x}10^{12}$ GJ per annual (Akintunde and Ogundari, 2019). This is several times more than the total energy demand of the country, which is estimated at $7.56\text{x}10^{10}$ GJ ($21\text{x}10^9$Kwh) (Adedeji and Onyinlola, 2018).

Consequently, wind energy is an immense natural energy resource that could be considered for integration into the national energy scheme.

Wind power could be utilized for many on-site applications in agriculture and engineering, and for electrical power generation. Example of on-site applications includes water pumping irrigation, grain grinding and food processing, lumbering and sea transport.

In case of electrical power generation, wind power systems could be designed to deliver AC or DC power consumption at the site or for connection into national electric power grind. In all cases of wind power utilization, a horizontal, vertical or variable axis wind turbine will have to be installed. The essential characteristics of wind turbines have been reported by (Florin and Eugen, 2019).

An important prerequisite for the utilization of wind power in any location is the evaluation of the wind energy potential of that location, and the determination of the proportion of the available wind energy that can be converted to technically usable energy based on the laws of nature and the available technology. This proportion depends essentially on the air density and the distribution of the wind speeds.

The purpose of this study is to summarize the basic principles for the assessment of the wind energy potential of any location. Routine meteorological data collected over twelve (12) years at the Nigerian Meteorological Agency (NIMET) Airport Station Benin-City, Edo State, Nigeria are used to illustrate the method.

## MATERIALS AND METHODS

The natural supply of wind power is defined as the rate of energy flow through a unit area normal to the direction of the wind.

Mathematically, this is given as

$$E_0 = 0.5rv^3 \quad (1)$$

Wind energy can be extracted using a machine called wind turbine. This converts the kinetic energy in the wind into rotational mechanical energy. Thus, equation (1) defines the power obtainable from an ideal wind turbine with ideal conversion efficiency. In reality, however, a unit conversion efficiency cannot be obtained with a wind machine; hence the useful power that can be extracted is reduced to

$$E = 0.5 \propto_d r v^3 \quad (2)$$

By making certain assumptions about the air-flow pattern, the theoretical maximum for the power coefficient, $\propto_d$ has been obtained as 16/27, or 0.59, but most practical turbines exceed a $\propto_d$ value of about 0.43.

The power coefficient, $\propto_d$, for a given machine will be fairly constant if the machine is operated close to the design conditions.

The wind power will therefore depend on the air density, r, and the wind velocity, v.

The air density, r depends on the temperature of the air, its moisture content and the prevailing barometric pressure, as well as the concentration of pollutants.

Neglecting the latter and treating a mixture of dry air and moisture as a perfect gas, an expression for the mean air density over a period of time is obtained as

$$r = \frac{P}{T}\left(\frac{T - HP_S/P}{R_1} + \frac{HP_S}{PR_2}\right) \quad (3)$$

The values of $R_1$ and $R_2$ can be obtained from tables of thermodynamic properties, while the annual average values of T, H and $P_s$ computed from the daily average for one or more years can be used. For instance, at Benin-City, values for T, H and $P_s$ in 2010 are given respectively as 300.38k, 0.674 and 4204N/m$^2$. The annual average barometric pressure for the location is used. Ideally, this should be computed over several years, but since the changes with time are very small, the average over shorter time periods could be used.

The average value for Benin-City in March 2009 is $0.99 \times 10^5$N/m$^2$ (that is, about 1 bar). Substituting these in equation (3) gives

r = 1.14kg/m$^3$

For Benin-City, at an elevation of approximately 280m above sea level, this figure compares well with 1.25kg/m$^3$ commonly used at sea level.

Like solar radiation intensity, the wind velocity varies greatly with time and space. Careful selection of the site for a wind machine must therefore be carried out.

Favoured locations should have high annual average wind speeds, rare occurrence of extreme wind turbulence and a dominating wind direction to minimize the area required by multi-unit plant. Coastal areas and hill tops usually fulfill these requirements.

For the operation and optimum design of a wind machine is any chosen place, the detailed structure of the wind velocity distributing over a period of 10 to 20 years needs to be known. For this purpose, routine meteorological data collection at the chosen or nearby site could be used since meteorological measurements are taken at 10m above the ground while wind turbines could be as high as 50 to 250m, Hellman's exponential law as applied by (Mostafaeipour et al; 2013) could be used to estimate the wind speed at any desired height h from measurements taken a base height $h_0$. This is given as

$$V = V_0\left(\frac{h}{h_0}\right)^a \quad (4)$$

This Hellman exponent, "a", is about 0.1429 for coastal locations, and 0.2 to 0.3 for forested regions.

Thus, assuming a = 0.25 for Benin-City, the average annual wind speed for the 12 years 2010 to 2021 increases from the value of 1.445m/s at a height of 10m to about 2.16m/s at a height of 50m. Noting that wind power follows a cubic law variation with respect to the wind speed, the foregoing increase in wind speed of only 50% results in wind power increase of over 230%. This illustrates the justification for building high towers for wind power installations.

## RESULTS AND DISCUSSION

Routine meteorological measurements of wind flow are often obtained with integrating cup anemometers, the wind runs being recorded at 9.00 and 15.00 hours. Consequently, only daily average values could be obtained from such data.

Typical daily average values for Benin-City are given in figure 1

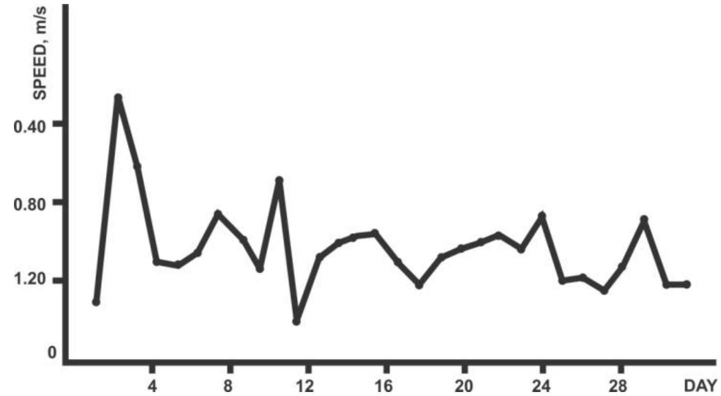


Figure 1: Daily Mean Wind Speeds at Benin-City April, 2021

By summing the daily average values for each month and each year, the monthly and annual mean wind speeds was obtained. Measured values for Benin-City for the period 2010 to 2021 are given in Table 1

**Table 1: Measured values of monthly and annual mean wind speeds for the period 2010 to 2021**

| | 2010 (m/s) | 2011(m/s) | 1012 (m/s) | 2013 (m/s) | 2014 (m/s) | 2015 (m/s) | 2016 (m/s) | 2017 (m/s) | 2018 (m/s) | 2019 (m/s) | 2020 (m/s) | 2021 (m/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 1.98 | 1.81 | 1.81 | 1.79 | 1.77 | 1.81 | 1.60 | 0.91 | 0.98 | 0.86 | 0.80 | 0.65 |
| Feb | 1.96 | 1.80 | 1.80 | 1.78 | 1.76 | 1.80 | 1.61 | 0.90 | 0.99 | 0.85 | 0.82 | 0.63 |
| March | 1.98 | 1.79 | 1.82 | 1.79 | 1.78 | 1.81 | 1.60 | 0.92 | 0.99 | 0.86 | 0.81 | 0.71 |
| April | 1.95 | 1.78 | 1.81 | 1.79 | 1.77 | 1.81 | 1.60 | 0.91 | 0.97 | 0.86 | 0.81 | 0.69 |
| May | 1.98 | 1.80 | 1.82 | 1.78 | 1.78 | 1.80 | 1.61 | 0.90 | 0.98 | 0.84 | 0.81 | 0.71 |
| June | 1.96 | 1.81 | 1.82 | 1.77 | 1.77 | 1.83 | 1.62 | 0.90 | 0.99 | 0.84 | 0.82 | 0.68 |
| July | 1.90 | 1.77 | 1.82 | 1.79 | 1.79 | 1.82 | 1.61 | 0.91 | 0.99 | 0.86 | 0.81 | 0.77 |
| Aug. | 1.98 | 1.80 | 1.81 | 1.78 | 1.80 | 1.81 | 1.60 | 0.90 | 0.98 | 0.86 | 0.82 | 0.70 |
| Sep. | 1.96 | 1.80 | 1.81 | 1.79 | 1.81 | 1.82 | 1.60 | 0.91 | 0.97 | 0.85 | 0.81 | 0.68 |
| Oct. | 1.99 | 1.78 | 1.80 | 1.79 | 1.78 | 1.82 | 1.60 | 0.90 | 0.99 | 0.85 | 0.81 | 0.69 |
| Nov. | 1.99 | 1.79 | 1.81 | 1.78 | 1.81 | 1.81 | 1.61 | 0.91 | 0.99 | 0.86 | 0.80 | 0.70 |
| Dec. | 1.99 | 1.78 | 1.80 | 1.78 | 1.79 | 1.82 | 1.60 | 0.92 | 0.98 | 0.86 | 0.81 | 0.71 |
| Mean | 1.97m/s | 1.80 | 1.81 | 1.78 | 0.78 | 1.82 | 1.61 | 0.91 | 0.98 | 0.85 | 0.81 | 0.70m/s |

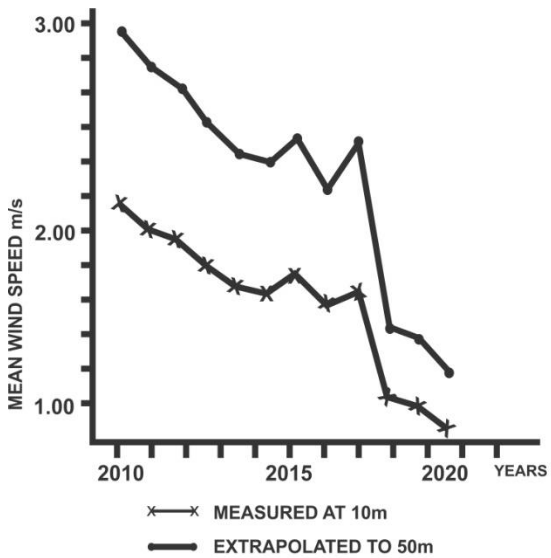


Figure 2: Annual Mean Wind Speeds at Benin-City

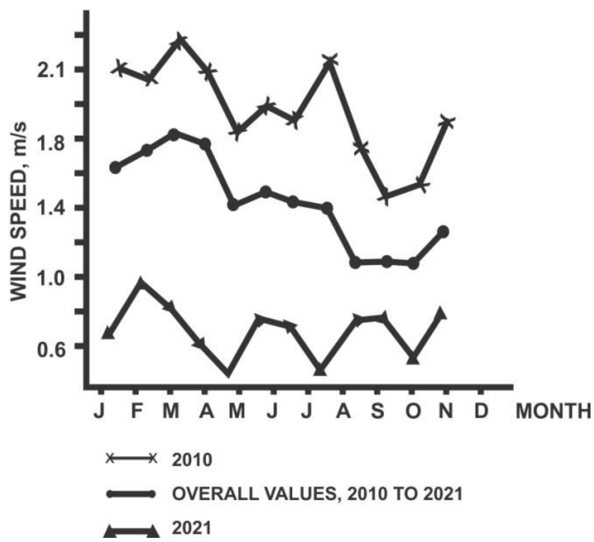


Figure 3: Monthly Mean Wind Speed, at Benin-City

In the design of wind turbines, it is common practice to design the wind machine to switch on automatically when the wind speed is above a certain minimum or cut-in speed, $V_{min}$, and to switch off when it is above an operationally safe maximum or cut-out speed, $V_{max}$. In most cases, $3\leq V_{min}\leq 6$m/s and $20\leq V_{max}\leq 30$m/s. It follows then that not only should the mean annual, monthly and daily mean wind speeds be analyzed but also the hourly wind speed distribution for one or more years. This result is in agreement with the work of Boluwaji et al., (2017). This is required in order to calculate the relative frequency and the relative cumulative frequency distribution of the wind speeds.

The relative frequency distribution of the wind speed is obtained by counting the number of hours in a period of time (say a year) that the velocity is within certain range, as shown in figure 4.

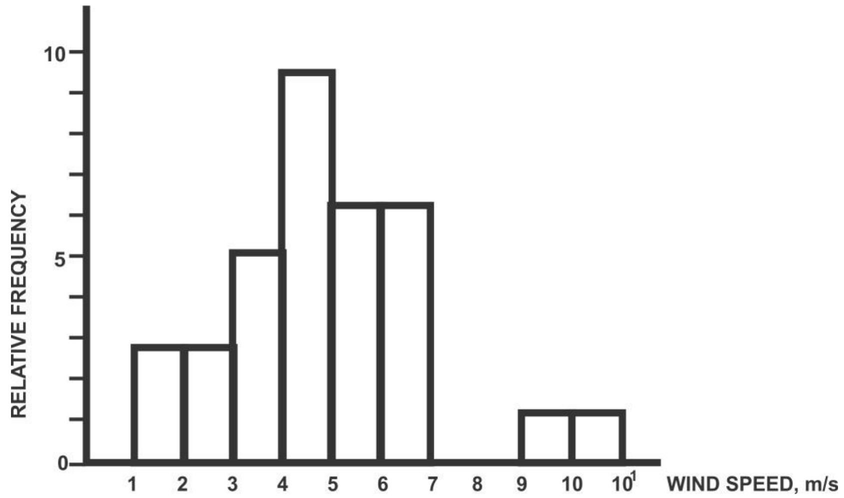


Figure 4: Relative Frequency Distribution of Wind Speeds at Benin-City 1st, 3rd and 5th April, 2022

From this, the relative cumulative frequencies could be obtained. These indicate which proportion of the hourly mean wind speeds is smaller than or equal to a given value. In the same way, that proportion of the wind speeds which are greater than a given maximum (or cut-out) values can be established. This result compared favourably with that obtained by Justus et al., (1978). Figure 5 gives an example of the relative cumulative frequency distribution for Benin-City.

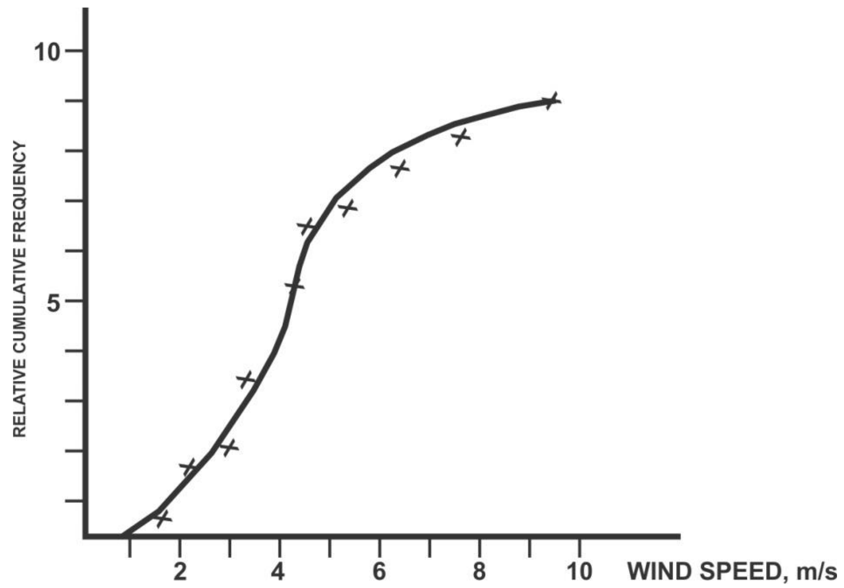


Figure 5: Relative Cumulative Frequency of Wind Speeds at Benin-City, 1st, 2nd, 3rd and 5th April, 2022

The determination of the frequency distributions help towards determining how long the wind power plant is likely to be out of action in the case of lack of wind, the range of the most frequent wind speeds and how often the wind power plant could achieve its rated output. (Ordonez and Osma, 2013)

Apart from the frequency distribution of speeds, the variance and the daily time evolution also need to be considered. This is especially so if the power plant is to be used for grid electricity generation or for on farm utilization. The variance is of particular significance for wind power utilization. The smaller the variance of wind speeds the more regular and therefore the higher values are the wind power production.

In the case of the time evolution, it is of great significance if the wind-derived electric power is to be integrated into the national electric power grind. Since the highest electricity demand occurs in the midday period and early evening, with the lowest in the very early morning, the pattern of wind speeds at those times should be ascertained for each day, the daily values being used to obtained the average monthly and annual values.

## CONCLUSION

The need to include wind power in the renewable energy resources development in Nigeria has been identified and a general method of evaluation of the wind energy potential of any location has been presented. The method has been illustrated using routine meteorological data collected at Benin-City between 2010 and 2021 and more refined 2022 data. It is shown that a reliable assessment of the wind energy potential of any location would require a detailed analysis of the daily and monthly mean wind velocity values for many years. In addition, the hourly mean values for a year or more would need to be analyzed for a reliable estimation of the wind power yields. Many potential sites exist in Nigeria for wind power utilization, especially in the coastal regions and hilltops in the hinter land. Time is therefore ripe, perhaps for a qualitative analysis of the wind energy potential at these locations.

## REFERENCES

Adedeji, A. S, & Oyinlola O. O (2018) Energy consumption and economic growth in Nigeria: An empirical analysis. *Journal of Energy Economics and Policy* (2018), 14 (3), 389-399. https://doi.org/10.36096/brss.v112.138

Akintunde, O. A; & Ogundari, O. O (2019) Energy demand and supply in Nigeria: *A Review Journal of Energy and Natural Resources* 8 (4), 229-242

Ale, T. & Adeyemi, A. (2022). Electricity demand pattern and supply availability on Nigeria grid system. *Journal of Applied Science Process Engineering* 9(1), 1042-1053. https://doi.org/10.33736/jaspe.4z64.2022

Boluwaji, O; Oyedum, O.D; Ugwuoke, P.E; & Abolarin, M. (2017). Assessment of wind energy resources in Nigeria-a case study of North-Western Region of Nigeria. International Journal of Physical Research, 5(2), 83-90. https://doi.org/10.14419/ijpr.v5i2.8327

Boro, D., Thierry, K; Kieno, F.P; & Bathiebo, J. (2020) Assessing the Best Fit Probability Distribution Model for Wind Speed Data for Different Sites of Burkina Faso. *Current Journal of Applied Science and Technology*, 39(22), 71-83

Dikko, I., & Yahaya, D.B. (2012). Evaluation of Wind Power Density in Gombe, Yola and Maiduguri, North Eastern Nigeria, *Journal of Research in Peace, Gender and Development*, 2(5), 115-122

Ezekwe, C. I & Ezeilo, C. O (1981). Measured solar radiation in a Nigerian environment compared with predicted data. *Solar Energy*, 26, 181-186. https://doi.org/10.1016/0038.092x(81)90083-9

Florin, O; & Eugen, R. (2019). An Assessment of Wind Energy Potential in the Caspian Sea. *Energies*, 12(13), https://doi.org/10.3390/en12132525

Justus, C. G; Hargraves, W.R; Mikhail, A; & Grabber, D. (1978): methods for Estimating Wind Speed Frequency Distributions, *Journal of Applied Meteorology* 17(3),350-353. https://doi.org/10.1175/15200450(1978)017<0350:MFEWSFY

Ordonez, G; Osma, G; Vergara, P; & Rey, J. (2013). Wind and Solar Energy Potential Assessment for Development of Renewable Energies Application in Bucaramanga, Columbia. *The international congress of Mechanical Engineering and Agricultural Sciences*, 59, 1-6. https://doi.org/10.1088/1757-899x/59/1/012004.

Tonsic, D; Tiam, K.P; & Tchuen, G. (2021) Wind Energy of Cameroon by determining Weibull parameters: potential of an environmentally friendly energy. *International Journal of Environmental Science Technology* 18, 2251-2270

Wilczak, J. M; Bianco, L. S; & Mc Caffeine, K. (2019). Identification and characterization of persistent cold pool events from temperature and wind profilers in the Columbia River Basin. *Journal of Applied Meteorology and Climatology*, 58 (12), 2533-2551.