Performance evaluation of wind turbines for sites in Chad

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ABSTRACT

For the production of electricity, the use of wind energy has become more interesting in recent years. In this present study, the authors assessed wind potential using wind speed data measured at 10 m altitude for a period of 18-30 years in Chad. The statistical method of Rayleigh's law was deployed in this study. In addition, the performance of five wind turbines in five different sites were examined based on their capacity factor and annual energy production. The results shows that the average monthly velocities of the five sites range from 2.54 m/s to 3.25 m/s and the power density varies from 20.80 W/m² to 44.17 W/m². By focusing on the annual energy production of these turbines, the results obtained show that the Enercon E-82 can be adapted for all the five sites.

1. Introduction

In the electricity generation sector, renewable energy sources have received particular attention due to the pollution caused by traditional systems as well as population growth [1]. The energy generated by fossil fuels and the combustion of coal produces dangerous gases (hydrocarbons, carbon monoxide, ionizing radiation, hydrochloric acid, etc.) which can degrade the environment. To overcome the problems of environmental degradation and pollution, renewable energy resources such as solar, wind etc. are very suitable. To make up for the lack of hydropower during the dry season, emphasis is placed on the use of wind turbines [2]. Wind energy has become a cheaper source in recent decades as it avoids environmental degradation and is inexhaustible. Thus, based on the linear regression model of the Weibull distribution, the analysis of wind speed data for four locations in Ireland was performed [3]. The global technique for extracting wind energy that is renewable, inexhaustible, sustainable, non-polluting and profitable is the use of modern wind turbines. An experimental study on new vertical axis wind turbines has been carried out. It traces the evolution of this knowledge and assesses the implications of these discoveries in terms of global warming [4, 5]. The demand for wind energy in Africa over the past decades has increased exponentially due to the economic and population growth of the countries. To ensure security of energy supply and an energy mix less dependent on hydrocarbons, they have favored renewable energies, in particular solar, wind, hydraulic, biomass, etc. [6]. In Chad, only 8% of the population has access to electricity, with a significant gap between rural (1%) and urban (20%) areas. Chad is one of the countries with the lowest electricity access rates in the world. Paradoxical situation with regard to the natural resources available to the country, in particular oil and renewable energies. Apart from the 1 MW wind power plant (composed of 4 wind turbines) in Amdjarass, a city located in the East of the country, electricity is now only supplied by generators, which regularly break down. Oil, which is used to run the groups, is a non-renewable, an expensive, and very polluting energy source. This situation hinders the socio-economic development of the country and affects the quality of life of the population [7]. As wind energy is increasingly becoming a major area of development in the coming years, it is a good idea to motivate researchers on the benefits of the said field. Given the importance given by electrical systems to the wind potential, efforts are made to study the production of electrical energy as well as the behavior of the wind [8]. To date, in several countries of the world, several works have been carried out on the potential as well as its characteristics. The authors conducted a technical and economic study of wind turbines in Nigeria [9]. In addition to this, they ranked the sites based on their wind energy densities, estimated capacity factor value, and present value cost. The authors did a study on the performance of wind turbines in Nigeria [10]. The annual energy production and the capacity factor of these turbines have been determined. While the authors were interested in energy potential and wind speed in China [11]. For the use of wind energy and optimize the production and transmission of electricity on the network for better performance of the system, the results should help decision makers to identify favorable areas. The authors made a statistical analysis of power density and wind speed of Jumla based on Rayleigh and Weibull models. Thus, the result showed a good approximation for the power density estimation with a maximum error of 3.68%

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Moreover, authors in were interested in studying the density distribution of wind energy, using the Rayleigh probability density function [13]. The Rayleigh distribution function was derived from available data. Furthermore, authors conducted a study on power generation as well as wind speed characteristics in Lithuania [14]. The study was focused on two regions and wind speed data were collected using an anemometer. To estimate the scale and shape parameters, a new mathematical model was developed. Several wind turbines have been selected to maximize the annual energy production and the selected wind turbines operate at lower wind speeds [15]. In reference [16], the authors selected several wind turbines whose nominal power varies from 1,104 W to 16,5104 W in their study on the evaluation of wind potential. The optimization by HOMER seems adapted to meet the demand for electrical energy. Authors studied the wind energy potential for sites in Bushehr province in Iran [17]. A comparison of the results for wind turbines indicates that the Proven 15 has the highest capacity factor. While authors compared wind resources by implementing a methodology for two Moroccan sites [18]. The comparison is based on wind data collected from two masts at heights of 30.50 and 60 m. Indeed, in the State of Chunuk, on the island of Weno, a meteorological observation mast is installed to assess the wind potential. Using the Rayleigh distribution, the annual energy production of a 20 kW wind turbine should be approximately 36841.73 kW h/year [19]. Using different methods to determine the Weibull parameters in two regions of Morocco, the investigation of the wind potential was carried. The highest values of wind potential occur during the months of March, July, September and December in Dakhla and during the months of December to March in Taza [20]. The electrical performances of some new wind turbines that have been the subject of an experimental study are presented. The results obtained show that the curved blade wind turbine with 3 blades configuration performs better than the other two configurations, i.e. 2 blades and 4 blades [21]. In reference [22], the authors conducted an experimental and even analytical analysis on the bladeless turbine for the incompressible fluid. Correlations between performance parameters are examined in experiments. In the present study, the performance evaluation of wind turbines for sites in Chad is conducted. In the first part, the wind speeds at different heights as well as the monthly distribution were discussed and analyzed. To study wind energy and energy production at different heights, the Rayleigh distribution function is deployed. In the second part, five wind turbines were chosen whose power varies from 1, 500 kW to 2,300 kW, the general objective is to determine the most appropriate turbine to install for each of the sites. The choice is based on the energy capacity calculation and energy production.

2. Wind data and analysis

In this study, monthly wind speed data for a period of 18–30 years were obtained from the General Directorate of National Meteorology in N'Djamena, Chad. The data obtained were recorded at a wind speed of 10 m using an anemometer. Thus the four sites namely, Faya-Largeau in the N'Djamena, Chad. The data obtained were recorded at an altitude of 10 m for the energy capacity factor calculation and energy production. Appropriate turbine to install for each of the sites. The choice is based on wind speeds at different heights as well as the monthly distribution were presented. The results obtained show that the curved blade wind turbine with 3 blades configuration performs better than the other two configurations, i.e. 2 blades and 4 blades [21]. In reference [22], the authors conducted an experimental and even analytical analysis on the bladeless turbine for the incompressible fluid. Correlations between performance parameters are examined in experiments. In the present study, the performance evaluation of wind turbines for sites in Chad is conducted. In the first part, the wind speeds at different heights as well as the monthly distribution were discussed and analyzed. To study wind energy and energy production at different heights, the Rayleigh distribution function is deployed. In the second part, five wind turbines were chosen whose power varies from 1, 500 kW to 2,300 kW, the general objective is to determine the most appropriate turbine to install for each of the sites. The choice is based on the energy capacity calculation and energy production.

2.2. Wind turbine performance parameters

The operation of a wind energy conversion system can only be done at its maximum efficiency as its design is made for a given site. Thus, the nominal wind speed (Ve), the cut-off wind speed (Vc), the nominal power (Pn), and the switch-on wind speed (Vc) must take into account the site wind characteristics. However, it is not easy to manufacture a wind turbine for one site and plan for each application. Therefore, it is important to make a choice in such a way as to maximize the amount of wind energy available. The total energy extracted by a wind system according to the Weibull distribution function is given in [33, 34] as:

\[
P_t = P_n \left\{ \frac{e^{-\left(\frac{v}{V_c}\right)^{\beta}} - e^{-\left(\frac{v}{V_m}\right)^{\beta}}}{\left(\frac{V_m}{V_c}\right)^{\beta} - 1} \right\}
\]

For Rayleigh distribution function given in equation (9), k is taken to be 2. The capacity factor is an important parameter for evaluating the performance of the wind turbine in addition to the total energy extracted by the system. It is expressed by Eq. (10):

\[
f(v) = \frac{\pi}{2} \left( \frac{v}{v_m} \right) \exp \left[ -\frac{\pi}{4} \left( \frac{v}{v_m} \right)^2 \right]
\]
The capacity factor is usually between 0.25 and 0.40 for a profitable wind energy investment. With $C_i \geq 0.40$ shows a strong interaction between the environment and the wind system [31].

The total energy production and revenue of a system, as well as its economic viability for a given site is determined by the capacity factor ($C_i$) and the total energy extracted ($P_T$).

### 3. Results and discussion

In this section, the data used and results from the proposed method were presented and discussed.

#### 3.1. Wind speed parameters

Tables 1a, 2, 3, 4, and 5 display the data for the five different sites considered in this study. Table 1b presents the different values of the parameters $v$, $c$, $v_F$, $v_E$, and $P_D$ for the Abeche site. This table shows that the minimum and maximum values are respectively $v$ (2 m/s; 3.1 m/s); $c$ (2.03; 3.50); $v_F$ (1.44 m/s; 2.47 m/s); $v_E$ (2.87 m/s; 4.95 m/s) and $P_D$ (9.36 W/m$^2$; 34.87 W/m$^2$).

Table 2 also presents the different values of the parameters $v$, $c$, $v_F$, $v_E$, and $P_D$ for the Faya-Largeau site. This table shows that for each of the parameters, the minimum and maximum values are respectively $v$ (2.2 m/s; 4 m/s); $c$ (2.48; 4.51); $v_F$ (1.76 m/s; 3.35 m/s); $v_E$ (3.83 m/s; 6.70 m/s) and $P_D$ (16.18 W/m$^2$; 86.71 W/m$^2$). Table 3 presents the different values of the parameters $v$, $c$, $v_F$, $v_E$, and $P_D$ for the Mongo site. This table shows that for each of the parameters, the minimum and maximum values are respectively $v$ (2 m/s; 3.3 m/s); $c$ (2.26; 3.72); $v_F$ (1.60 m/s; 2.63 m/s); $v_E$ (3.19 m/s; 5.27 m/s) and $P_D$ (9.36 W/m$^2$; 42.06 W/m$^2$).

#### Table 2. Different monthly values of the parameters of Faya-Largeau

| Months | $V_m$ (m/s) | $C$ (m/s) | $V_F$ (m/s) | $V_E$ (m/s) | $P_D$ (W/m$^2$) |
|--------|-------------|-----------|-------------|-------------|-----------------|
| January | 4.063 | 2.873 | 5.746 | 54.605 |
| February | 4.515 | 3.192 | 6.385 | 74.904 |
| March | 4.740 | 3.352 | 6.704 | 86.711 |
| April | 3.612 | 2.554 | 5.108 | 38.351 |
| May | 3.612 | 2.554 | 5.108 | 38.351 |
| June | 4.063 | 2.873 | 5.746 | 54.605 |
| July | 3.612 | 2.554 | 5.108 | 38.351 |
| August | 2.822 | 1.995 | 3.990 | 18.287 |
| September | 2.709 | 1.915 | 3.831 | 16.179 |
| October | 2.709 | 1.915 | 3.831 | 16.179 |
| November | 3.725 | 2.634 | 5.267 | 42.060 |
| December | 3.837 | 2.713 | 5.427 | 46.001 |
| Average | 3.250 | 2.668 | 2.594 | 5.188 | 43.716 |

#### Table 3. Different monthly values of the parameters of Ndjamena.

| Months | $V_m$ (m/s) | $C$ (m/s) | $V_F$ (m/s) | $V_E$ (m/s) | $P_D$ (W/m$^2$) |
|--------|-------------|-----------|-------------|-------------|-----------------|
| January | 3.6 | 4.063 | 2.873 | 5.746 | 54.605 |
| February | 4 | 4.515 | 3.192 | 6.385 | 74.904 |
| March | 4.2 | 4.740 | 3.352 | 6.704 | 86.711 |
| April | 3.2 | 3.612 | 2.554 | 5.108 | 38.351 |
| May | 3.2 | 3.612 | 2.554 | 5.108 | 38.351 |
| June | 3.6 | 4.063 | 2.873 | 5.746 | 54.605 |
| July | 3.2 | 3.612 | 2.554 | 5.108 | 38.351 |
| August | 2.5 | 2.822 | 1.995 | 3.990 | 18.287 |
| September | 2.4 | 2.709 | 1.915 | 3.831 | 16.179 |
| October | 2.4 | 2.709 | 1.915 | 3.831 | 16.179 |
| November | 3.3 | 3.725 | 2.634 | 5.267 | 42.060 |
| December | 3.4 | 3.837 | 2.713 | 5.427 | 46.001 |
| Average | 3.250 | 3.668 | 2.594 | 5.188 | 43.716 |

#### Table 4. Different monthly values of the parameters of Moundou.

| Months | $V_m$ (m/s) | $C$ (m/s) | $V_F$ (m/s) | $V_E$ (m/s) | $P_D$ (W/m$^2$) |
|--------|-------------|-----------|-------------|-------------|-----------------|
| January | 3.1 | 3.499 | 2.474 | 4.948 | 34.867 |
| February | 3.3 | 3.725 | 2.634 | 5.267 | 42.060 |
| March | 3.1 | 3.499 | 2.474 | 4.948 | 34.867 |
| April | 3.3 | 3.725 | 2.634 | 5.267 | 42.060 |
| May | 2.9 | 3.273 | 2.314 | 4.629 | 28.544 |
| June | 2.8 | 3.160 | 2.235 | 4.469 | 25.692 |
| July | 2.7 | 3.047 | 2.155 | 4.217 | 22.499 |
| August | 2.3 | 2.596 | 1.836 | 3.671 | 14.240 |
| September | 2.1 | 2.370 | 1.676 | 3.352 | 10.839 |
| October | 2 | 2.257 | 1.596 | 3.192 | 9.363 |
| November | 2.1 | 2.370 | 1.676 | 3.352 | 10.839 |
| December | 2.6 | 2.935 | 2.075 | 4.150 | 20.571 |
| Average | 2.6917 | 3.038 | 2.148 | 4.296 | 24.748 |

where $P_T$, $V_{ci}$, $V_{co}$ et $V_r$ represent the rated power of the turbine, cut-in wind speed, cut-out wind speed and rated wind speed.
Tables 7, 8, and 9 present the different monthly values of $C_T$ and $E_{WT}$ of five wind turbines for three sites in Chad respectively, N'Djamena, Moundou and Mongo. For the N'Djamena site, the minimum and maximum values are respectively $C_T$ (1.69%; 7.46%) and $E_{WT}$ (27962 kW h; 123564 kW h) for Enercom E-82, Enercom E-90, Nordex S77, and Vestas V90-2 respectively. For the Moundou site, the minimum and maximum values are respectively $C_T$ (0.54%; 4.53%) and $E_{WT}$ (9010 kW h; 155660 kW h) for Nordex, and Vestas V90-2 respectively. For the Mongo site, the minimum and maximum values are respectively $C_T$ (1.92%; 10.45%) and $E_{WT}$ (27707 kW h; 150410 kW h) for Nordex and Vestas V90-2 respectively.

Similarly, Tables 10 and 11 present the monthly values of $C_T$ and $E_{WT}$ of five wind turbines for the Faya-Largeau and Abeche sites respectively. For the Faya-Largeau site, the minimum and maximum values are respectively $C_T$ (0.92%; 5.43%) and $E_{WT}$ (13215 kW h; 78248 kW h) for Nordex and Vestas V90-2 respectively. For Abeche site, the minimum and maximum values are respectively $C_T$ (1.35%; 9.40%) and $E_{WT}$ (11050 kW h; 142410 kW h) for Vestas V90-2 respectively.
respectively $C_f$ (1.28%; 6.65%); $E_{WT}$ (21176; 110092) for Enercom70. Enercom E-82, $C_f$ (1.95%; 10.15%) and $E_{WT}$ (28123 kW h; 146165 kW h). Nordex 90, $C_f$ (0.90%; 8.19%) and $E_{WT}$ (14822 kW h; 135627 kW h), Nordex S77, $C_f$ (0.90%; 8.19%) and $E_{WT}$ (9667 kW h; 88453 kW h). Finally, Vestas 90, $C_f$ (1.37%; 9.21%) and $E_{WT}$ (19974 kW h; 132696 kW h). The profitable wind turbine in terms of capacity factor is Enercom E-82. As for the Abeche site, the minimum and maximum values are respectively $C_f$ (0.05%; 0.42%); $E_{WT}$ (827 kW h; 6965 kW h) for Enercom70. Enercom E-82, $C_f$ (0.10%; 0.67%) and $E_{WT}$ (1487 kW h; 9719 kW h). Nordex 90, $C_f$ (0.07%; 0.26%) and $E_{WT}$ (1137 kW h; 4250 kW h), Nordex S77, $C_f$ (0.07%; 0.26%) and $E_{WT}$ (742 kW h; 2772 kW h). Finally, Vestas 90, $C_f$ (0.09%; 0.44%) and $E_{WT}$ (1238 kW h; 6290 kW h). The profitable wind turbine in terms of capacity factor is Enercom E-82.

### 3.2. Wind turbine performance assessment

The wind turbine performance assessment was carried out yearly as given below.

#### 3.2.1. Annual energy output

Table 12 presents the annual values of $C_f$, Pout and $E_{WT}$ of five wind turbines chosen for the five selected sites in Chad namely Faya-Largeau, Enercom E-82, Nordex S77 and Vestas 90.

The results in Tables 7, 8, 9, 10, and 11 for the calculations of $C_f$ and $E_{WT}$ are supported by the works of authors in [19, 20].
Moundou, N'Djamena, Mongo and Abeche. It can be seen that the minimum and maximum values of each wind turbine are respectively: Enercom E-70 (1.87%; 50.02%); Enercom E-82 (3.32%; 76.38%); Nordex N90 and Nordex S77 (1.69%; 56.29%) and Vestas V90-20 (2.44%; 66.45%) whose sites are respectively Abeche and Faya-Largeau.

### 4. Conclusion

This article examined the performance of five wind turbines as well as the assessment of wind energy potential for five sites in Chad. It appears that the power density varies from 20.80 W/m² to 44.17 W/m² respectively, minimum value for Mongo and maximum for Faya-Largeau. Focusing on the annual energy production, the Enercom E-82 wind turbine with a power of 200 kW and a nominal speed of 2 m/s could be adapted for the five sites considered in this study. The annual production of the said turbine is approximately 1,099,911 MW h, 659,189 MW h, 561,005 MW h, 313,089 MW h and 18,288 MW h respectively for the Faya-Largeau, Moundou, N'Djamena, Mongo and Abeche sites. In addition, for all the sites, the Nordex S77 wind turbine whose nominal power is 1,500 kW generates the lowest energy production produced 607.915 MW h, 313,089 MW h, 250,661 MW h and 18,288 MW h respectively for the Faya-Largeau, Moundou sites, N'Djamena, Mongo and Abeche. Moreover, if we focus on the capacity factor for the decision to be made, which gives the respective factors of 76.38% (Enercom E-82), 66.45% (Vestas V90-20), 56.29 (Nordex N90 and Nordex S77) and 50.02% (Enercom E-70).

### Declarations

**Author contribution statement**

Marcel Hamda Soulouknga and Tobiloba Emmanuel Somefun: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Serge Yamigno Doka: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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**Declaration of interest’s statement**

The authors declare no conflict of interest.

**Additional information**

No additional information is available for this paper.

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