American Journal of Energy Engineering
2023; 11(4): 120-126
http://www.sciencepublishinggroup.com/j/ajee
doi: 10.11648/j.ajee.20231104.13
ISSN: 2329-1648 (Print); ISSN: 2329-163X (Online)

Wind Data Assessment for Wind Power Production with a View to Reducing the Rate of Greenhouse Gas Emissions in the City of Abéché, Chad

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To cite this article:

Mahamat Adoum Abdraman, Yacoub Tidjani, Boukhari Mahamat Issa, Mahamat Kher Nediguina, Abakar Mahamat Tahir, Ruben Mouangue. Wind Data Assessment for Wind Power Production with a View to Reducing the Rate of Greenhouse Gas Emissions in the City of Abéché, Chad. *American Journal of Energy Engineering*. Vol. 11, No. 4, 2023, pp. 120-126. doi: 10.11648/j.ajee.20231104.13

Received: September 17, 2023; **Accepted**: October 23, 2023; **Published**: November 17, 2023

Abstract: The objective of this research work is to assess the wind potential of the city of Abéché, based on data provided over ten (10) years by the meteorological station of the National Meteorological Agency (ANAM) of Chad using daily wind data for a recording interval of one hour. Then, the mathematical model used to evaluate wind parameters is the Weibull distribution which is one of the most widely used distributions in several previous works for the assessment of wind potential. This mathematical model made it possible to accurately assess the wind power density and the energy density available at different altitudes: 10m, 30m, 50m and 80m. Then, a numerical simulation allowed us to identify the different wind turbinesapplicable to the study site. The result obtained from this work shows that wind turbines can only be installed for the production of electricity from a height of 30m in the Town of Abeche. The project will reduce 93% percent GHG emissions.

Keywords: Wind, Energy Conversion, Wind Rose, Greenhouse Gas, Abeché, TCHAD

1. Introduction

Energy consumption is growing very strongly in all regions of the world, due to the increase in the world population. Most of this energy is produced by fossil sources (oil, coal and gas). However, these sources have many disadvantages mainly their impacts on the atmosphere and the fact that they tend to run out since they are not renewable. Conventional energy sources can no longer meet demand. Thus, renewable energies are the ones that will soon impose themselves because of the ease of their exploitation. One of them is wind energy, which uses the kinetic energy of the wind. In 2016, renewable energy accounted for only about 20.2% of global electricity production [1]. Most countries on the African continent face a significant lack of access to energy. Energy, a fundamental pillar of economic, political and social development, nevertheless remains one of the main challenges they face. So these countries are endowed with abundant renewable energy resources that can make energy affordable, reliable and sustainable. Africa, with enormous wind potential, estimated at 1300 MW [2], but with a distribution that is not uniform as solar resources. Wind resources, of average quality to raise, are found in most of North Africa. Potential also exists in the Sahel region, in the mountainous regions of southern Africa (notably Lesotho, Malawi, South Africa, Zambia) and in parts of East Africa, particularly in the Horn of Africa and along the Great Rift Valley (Eritrea, Djibouti, Somalia, Ethiopia, Kenya and Tanzania) [2]. Chad, with an area of 1284000 km^2, is a landlocked landlocked country. The rate of access to electricity is among the lowest in Africa, between 2 and 4% of the mainly urban population [3]. However, the country has an important energy resource, including fossil (oil, uranium) and renewable energy (biomass, solar, wind etc.) [4]. Thus, in

2019, the share of renewable energies in the total real consumption in Chad amounted to about 77.8% [5]. Chad has a very large wind farm in the northern regions (where there are two mountain ranges), as well as in the central and southern regions. Unfortunately, all these enormous wind energy resources do not appear in Chad's energy balance mainly because of their low level of exploitation [6]. A part from the city of Amdjarass, wind power is not developed in the rest of the national territory. The need to enhance the value of exploitation of wind energy leads many researchers to reflect on the evaluation and estimation of these wind energies.

2. Presentation of the Study Area

Abéché is the capital of the Ouaddaï region and the Ouara department located at an altitude of 545m in the east of the country. Abéché is one of the largest cities in the province and the third largest in eastern Sahelian Chad. Site geographic coordinates are given in Table 1 and supported by Figure 1.

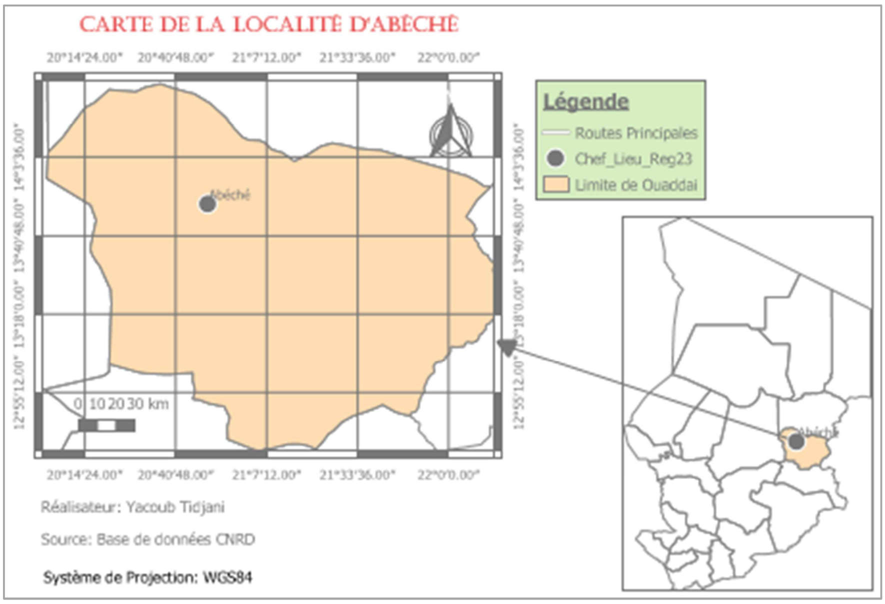

Figure 1. *Study area location Map.*

Table 1. *Geographical coordinates of the sites.*

Site	Latitude	Longitude	Altitude
Abéché	13,8N	20,8E	545m

3. Materiel and Methods

3.1. Wind Data Description and Source

The data used in this work are essentially wind speeds from 01/01/2012 to 31/12/2022 (10 years). This data is provided by the National Meteorological Agency. The measurements are taken per hour and at 10 m from the ground.

3.2. Mathematical Modelling

The Weibull distribution is a special case of the Pearson distribution [7]. In this distribution, variations in wind speed are characterized by two features: the probability density function and the cumulative distribution function. The probability density function f (v) indicates the fraction of time (or probability) for which the wind has given velocity v. It is given by [8-10]:

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

With *k* the form factor (without unit) and *c* the scale factor (m/s). The cumulative distribution function of the velocity *v* or Weibull cumulative distribution function F (v) gives the fraction of time (or the probability) for which the wind speed is less than or equal to v. It is given by [11, 12]:

$$F(v) = \int_0^v f(v)dv = 1 - exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{2}$$

The average wind speed according to the Weibull distribution is calculated by the following formula:

$$V_m = \int_0^\infty v\, f(v)dv = C\,\Gamma\left(1 + \frac{1}{k}\right) \tag{3}$$

The distribution of Weibull proves to be suitable for the description of the statistical properties of the wind [13, 14]. Knowing that the formula of the Gamma function is as follows:

$$\Gamma(n) = \int_0^\infty e^{-x} x^{n-1} dx \tag{4}$$

Where x = $(v/c)^k$ and n = 1 / (k + 1)

3.3. Estimates of Weibull Parameters

There are several methods for determining the parameters K and C from the wind data of a site. The most common are: the graphic method, method of moment, maximum likelihood method, the modified maximum likelihood method and the standard deviation method [8, 9]. Since wind data are available in the format of frequency distribution, the recommended method is the modified maximum likelihood method [13]. Weibull parameters are determined using equations (5) and (6):

$$k = \left(\frac{\sum_{i=1}^{n} v_i^k Ln(v_i) f(v_i)}{\sum_{i=1}^{n} v_i^k f(v_i)} - \frac{\sum_{i=1}^{n} Ln(v_i) f(v_i)}{F(v \geq 0)}\right)^{-1} \quad (5)$$

$$C = \left(\frac{1}{F(v \geq 0)} \sum_{i=1}^{n} v_i^k f(v_i)\right)^{\frac{1}{k}} \quad (6)$$

Where Vi is the midpoint of the interval of speeds i, n the number of intervals, f (Vi) the frequency for which the wind speed falls in the interval i, F (v = 0) the probability that the wind speed is greater than or equal to zero.

3.4. Roughness Modeling

The roughness, intuitively, would define obstacles seen from afar, or a set of very small obstacles brought back to the scale of the wind. Its data are empirical and there are no calculation formulas that are precise enough to represent a variety of movement and agitation of blades of grass, growing trees and cities that are being built. The roughness of a territory is very often parameterized by a length scale called roughness length. A simple empirical relationship between the roughness elements and the roughness length was formulated by Lettau in 1969 [14].

$$Z_0 = \frac{0.5(h.S)}{A_H} \quad (7)$$

Where h is the height of the roughness element (m), S, its cross-sectional area facing the wind (m 2) and AH, the average horizontal surface area in (m 2) delimiting the repartition of the roughness element in question.

4. Results and Discussion

4.1. Wind Potential

Figure 4 shows the monthly variation in the site's average wind speed at 10m height over a 10-year period. This figure shows that at 10m from the ground, five (05) months (December to April) are recorded with a high monthly average speed between 3.15 and 3.39m/s. The 7 months of very low speeds are recorded from May to November where the speed varies from 1.36 to 2.80m/s.

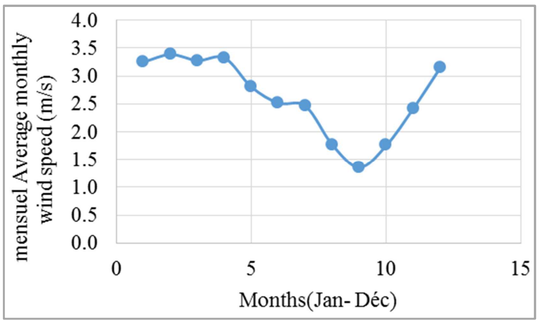

Figure 2. *Monthly wind speed variation.*

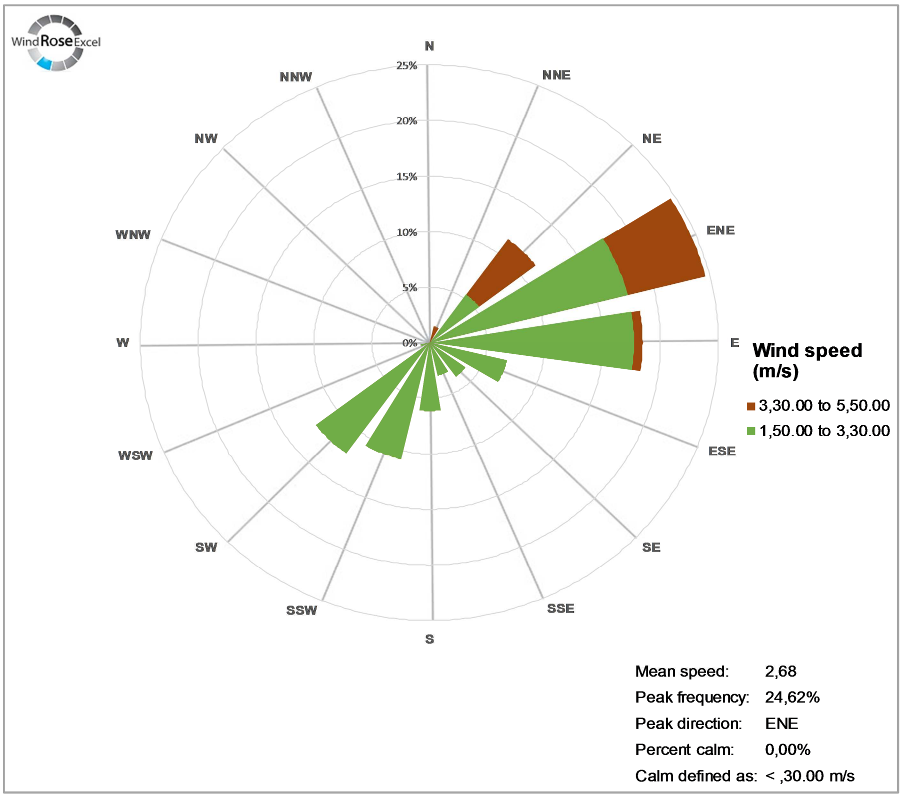

Figure 3. *Wind rose at 10m for representation of wind distribution.*

Figure 5 shows that there is a predominance of wind in October to May from East to Northeast and from June to September in the range of directions, South-West (SW) to South-South-West (SSO). The highest on the other hand is recorded in the East-North-East (ENE) direction from (November to April).

4.2. Probability Density Function

The frequency distributions of the site's monthly wind speeds are represented by the curve in Figure 3. This figure shows us that we have three months of very low wind speed which are clearly observed in the months of August, September and October with speeds between 1.36 and 1.76m/s. Applying the weibull law of cumulative frequency, we observe in Figure 4 that the maximum speeds that can be reached are less than or equal to three meters per second (3m/s) for the months of September and October. The other months have the speed range that extends up to 5m/s. This requires us to extrapolate average wind speed data.

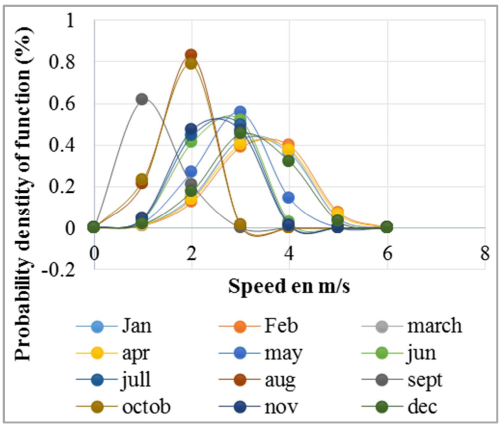

Figure 4. *Histogram of the wind speed frequencies modelled by the Weibull distribution.*

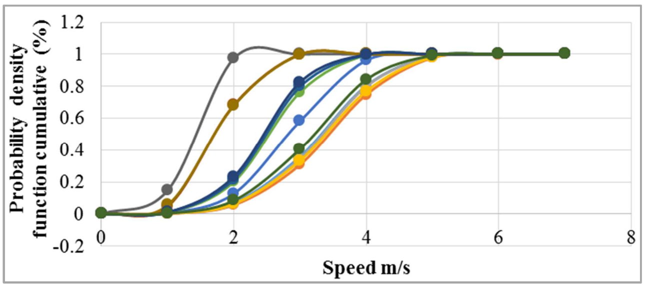

Figure 5. *Histogram of the cumulative frequencies of the wind speed modelled by the Weibull distribution.*

4.3. Evaluation of Weibull Parameters

The parameters of weibull k and c, calculated at 10m height for the site are presented in table 3. in this table it can be seen that the smallest value of the shape parameter k (k = 1.095) and the scale parameter c (c = 1.403m/s), in september and the maximum values of k and c are observed in february (k = 1.729) and (c = 3.799m/s). This demonstrates the low average speed value observed in September.

Table 2. *Parameters of Weibull.*

Months	Abéché			
	V (m/s)	K	C	P (W/m²)
January	3.25	1.70	3.64	44.76
Fébruary	3.39	1.72	3.80	49.27
March	3.28	1.70	3.74	45.60
April	3.32	1.71	3.73	47.14
May	2.80	1.57	3.12	31.56
Jun	2.52	1.49	2.78	24.70
Jully	2.46	1.47	2.72	23.53
August	1.76	1.25	1.80	11.48
September	1.36	1.09	1.40	6.84
October	1.76	1.25	1.88	11.38
November	2.42	1.46	2.67	22.60
Décember	3.15	1.67	3.53	41.48

4.4. Extrapolattion to Different Hights

Figure 6 shows the extrapolation of the average wind speed at different heights (10m, 30m, 50m and 80m). It can be seen that annual variations in wind speed increase with altitude at the site. This can guide the choice of height for the optimization of electricity production.

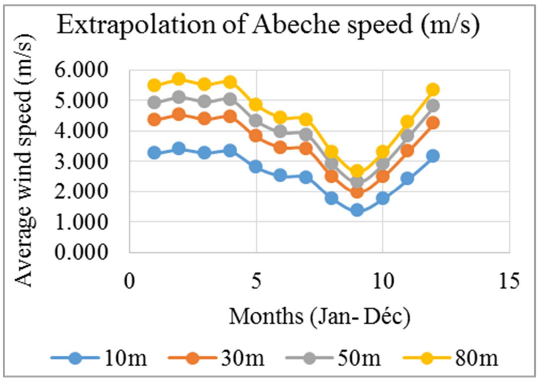

Figure 6. *Extrapolation of wind speeds at different heights.*

The extrapolation of the Weibull parameters is presented in table 4, it can be seen that the values of k vary very little on the site. The value of k goes from 1.09 (September, at 10m) to 1.80 (February at 80m). While c goes from 1.40m/s (September at 10m) to 1.80m/s (February at 80m). The proportionality of c with the average speed is demonstrated by the variation of c with height.

Table 3. *Extrapolation of k and c (Abeche).*

	Jan	Feb	March	Apr	May	Jun	Jull	Aug	Sept	Oct	Nov	Déc
Extrapolation de *k*												
10m	1.70	1.73	1.70	1.71	1.57	1.50	1.47	1.25	1.09	1.24	1.46	1.67

	Jan	Feb	March	Apr	May	Jun	Jull	Aug	Sept	Oct	Nov	Déc
30m	1.71	1.75	1.72	1.73	1.59	1.50	1.49	1.26	1.10	1.26	1.47	1.68
50m	1.74	1.77	1.74	1.75	1.61	1.53	1.51	1.28	1.12	1.27	1.50	1.71
80m	1.77	1.80	1.77	1.79	1.64	1.55	1.54	1.30	1.14	1.30	1.52	1.74
Extrapolation de *c*												
10m	3.64	3.80	3.67	3.73	3.11	2.78	2.72	1.89	1.40	1.88	2.67	3.52
30m	4.83	5.01	4.86	4.93	4.19	3.79	3.71	2.67	2.04	2.66	3.64	4.68
50m	5.43	5.63	5.47	5.54	4.75	4.30	4.22	3.09	2.38	3.07	4.15	5.28
80m	6.03	6.24	6.07	6.14	5.30	4.82	4.73	3.51	2.74	3.49	4.66	5.86

4.5. Power Density and Energy Density

Figure 7 shows us that wind power density increases with height. The analysis of the figure also shows that the energy density is proportional to the power density, the latter also increases with height.

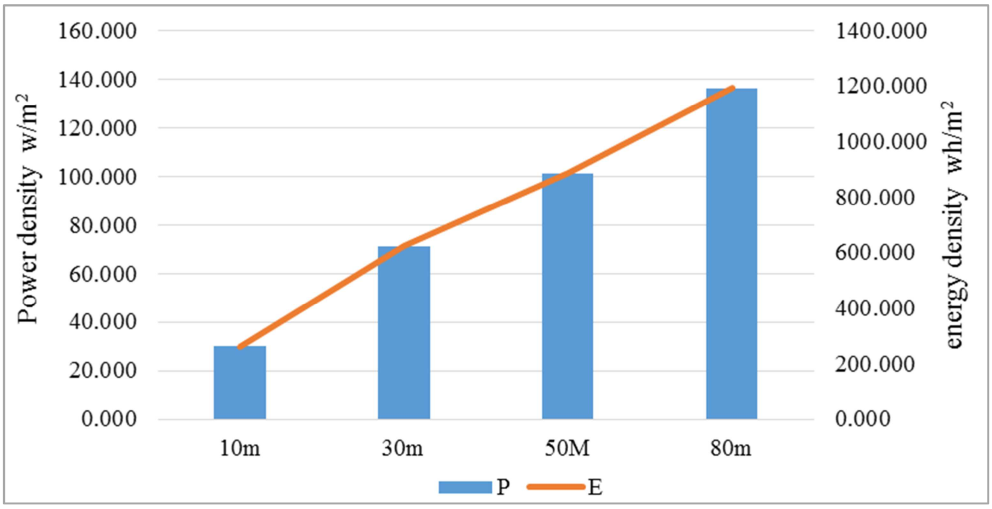

Figure 7. *Power density and energy at different heights.*

APPLICATION: CHOICE OF AEROGENERATOR

Table 4. *Characteristics of wind turbines.*

Characteristics	Aerogenerator1	Aerogenerator2	Aerogenerator3
Mast height	30m	50m	80m
Start-up speed	2.8m/s	2.5m/s	2m/s
Rated speed	6m/s	8m/s	10m/s
Stop speed	25m/s	25m/s	25m/s
Rotor diameter	15m	30m	82m

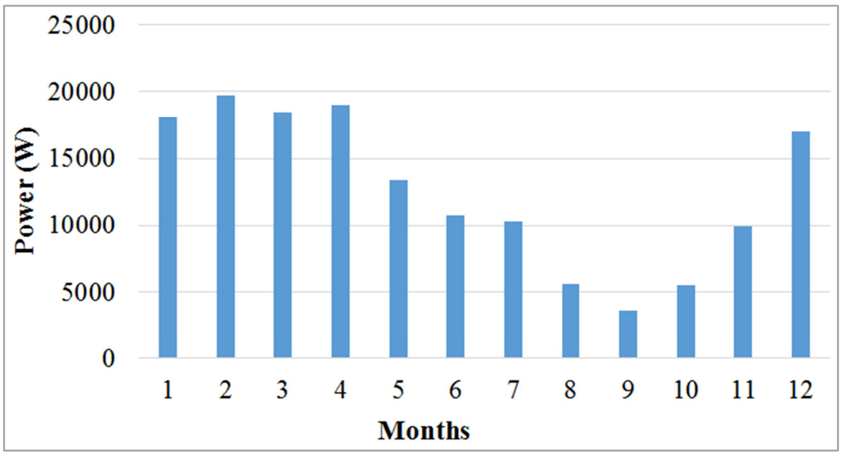

Figure 8. *Aerogenerator power 1.*

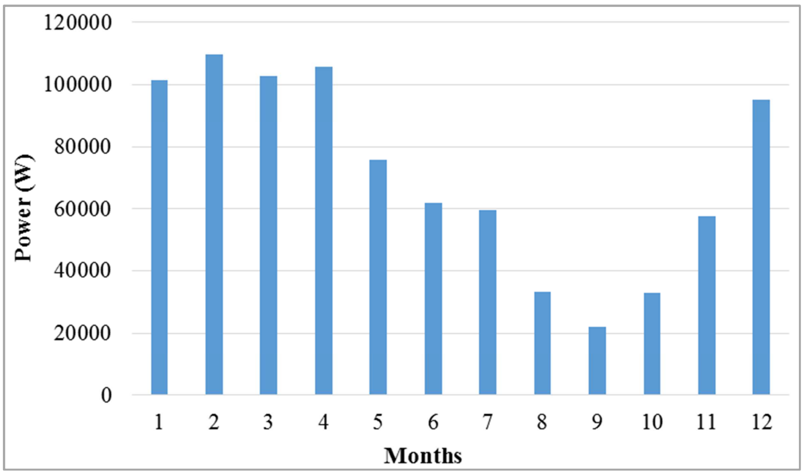

Figure 9. *Aerogenerator power 2.*

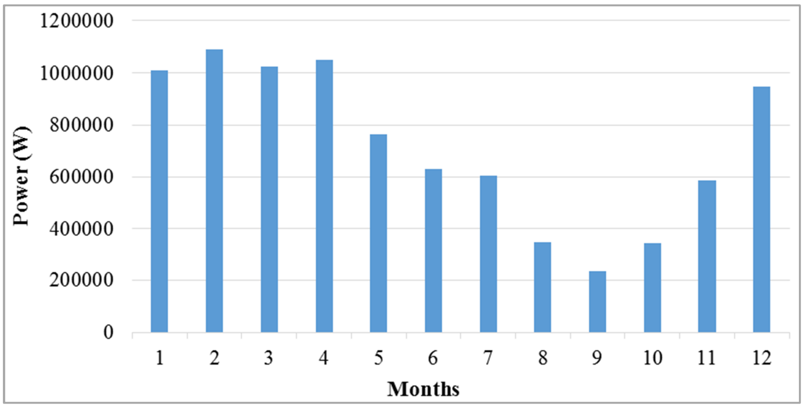

Figure 10. *Aerogenerator power 3.*

The extrapolation of wind power, clearly shows us the increase of power with height. Thus the lowest power observed in September goes from 3592.34 (at 30m) to 234948.98w (at 80m) and the maximum power observed in February goes from 19734.30 (at 30m) to 1088066w (at 80m).

The performance of wind turbines is estimated with the capacity factor (CF) which represents the fraction of the average power supplied by the wind turbine compared to the nominal power of the wind turbine [3]. We can only talk about electricity production from wind turbines if the load factor is at least 25% [3]. In Table 5, when the capacity factors of wind turbines are evaluated, we obtain respectively, for wind turbines: 1, 2, 3 capacity factors equal to 31%, 28% and 26%. It can therefore be concluded that these wind turbines have characteristics very close to those mentioned in the table below.

Table 5. *Characteristics of wind turbines.*

Characteristiques	EOLTEC-SIROCCO5.5-6	Fuhrlander FL250	Enercon
Mast height	30m	50m	80m
Rated power	9.5kw	71.48kw	719kw
Start-up speed	2.8m/s	2.5m/s	2m/s
Rated speed	6m/s	8m/s	10m/s
Stop speed	25m/s	25m/s	25m/s
Rotor diameter	15m	30m	82m

5. Conclusion

At ten (10) meters in height, the monthly average speeds are low ranging from 1.36m/s to 3.39m/s. These speed values are, at the limit lower than the starting speed of wind turbines. This is how we extrapolated the speeds to heights of 30m, 50m and 80m to obtain consistent speeds. This extrapolation made it possible to identify wind turbines applicable to the study site. Chad Emit approximately 55469tCO2 each year with a factor GHG emission of 0.204tCO2/MWh.

Acknowledgments

The authors express their sincere thanks to ASECNA-CHAD for weather data.

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