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**Research Paper** 

# **Evaluation of the Wind Power Potential in the Northeast of Chad**

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#### ABSTRACT

Chad has done the study and development of renewable resources a priority in its energy mix. Wind energy is one of the renewable sources that can help Chad to develop rural areas and preserve the environment. This study presents from data obtained from NASA, the wind characteristics in Amdjarass, and Fada over thirty (30) years. The wind distribution density and energy potential at different heights were evaluated using the Weibull statistical analysis method. The aim of this paper is to evaluate the wind energy potential of two important sites in Chad. The study shows that over the 30 years, the mean annual wind speeds vary randomly between 4.7 m/s and 5.4 m/s over an average period of 2 years. Eight months of good average wind speeds were recorded, ranging from 5.01 m/s to 6.31 m/s at Amdjarass and 4.92 m/s to 5.70 m/s at Fada. The 04 months of low velocities observed are in the range of 3.211 m/s - 4.064 m/s at Amdjarass and 3.504 m/s - 4.516 m/s at Fada. The power density varies between 21.53 W/m<sup>2</sup> and 111.89 W/m<sup>2</sup> in Amdjarass, while in Fada, it varies from 19.85 W/m<sup>2</sup> to 86.92  $W/m^2$ .

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#### 1. Introduction

Energy is a very important input for the socio-economic development of countries. Fossil fuels are the main resources that play a very important role in the world development. However, fossil fuel reserves are limited, exhaustible and usage of fossil fuel sources have negative environmental effects and produces gas emissions such as, carbon monoxide, hydrocarbons and ionization radiation [1, 2]. It is therefore essential to make the best use of renewable energy and to manage the available energy sources. Since the availability of new energy sources can alleviate this global problem. Wind has nowadays become a stable form of power supply and is considered as one of the most cost-effective means for delivering low-carbon energy services [3, 4].

Chad, with an area of 1,284,000 km<sup>2</sup>, is a landlocked country with no access to the sea. The rate of access to electricity is among the lowest in Africa, between 2 and 4% of the population essentially urban [5, 6]. However, the country has an important energy resource including fossil (oil, uranium) and renewable (biomass, solar, wind etc.).

Abdelhamid *et al.*, [7] demonstrated that electricity production in Chad is provided by the National Electricity Company in Ndjamena (the capital) and six (06) other provinces (Abéché, Bongor, Doba, Faya, Moundou and Sarh) out of 23 provinces. However, there are a few private operators who supply some towns. The source of energy production in all cases is oil.

The search for renewable energy sources and their promotion is a major concern for Chad, since they can provide a solution to the country's energy problems.

Wind energy is developing very rapidly on a global scale. Thanks to the improvement of technologies, the production of electricity by wind energy has reached a high level of technological maturity and industrial reliability [8, 9]. The further development of this source of energy could be useful for Chad's energy mix.

Some research studies show that the provinces of the Saharan zone of Chad, with an average wind speed of between 3.25 and 9 m/s, constitute the area of high wind potential for the production of electrical energy [7, 10].

Soulouknga *et al.*,[10] compared the wind energy potential of the three climatic zones of Chad (Saharan zone, Sudanian zone and the Sahelian zone) and concluded that the windiest zones are the Saharan and Sahelian zones with average annual wind speeds of 3.575 m/s and 3.25 m/s respectively.

Mahamat *et al.*, in 2016 evaluated the wind resource in the city of N'djamena in Chad. They showed that the installation of a wind farm of 10 Vestas V80/1.8 MW turbines at 100 meters

would produce 50,420 MWh of energy [11].

The objective of this paper, carried out in the north east of Chad, is to define the density of wind speed distribution of the provinces and to estimate from the data acquired from NASA, the wind potential available over thirty (30) years.

Given most of the previous work done on Chad, this study provides additional information on wind energy in Chad.

### 2. Materials and methods

#### Presentation of the study area

Amdjarass and Fada are the capitals of the East-Ennedi and West-Ennedi provinces in Northeast of Chad. Amdjarass is the largest city in the province and the fourth largest in Saharan (northern) Chad. Fada is a town located on the Ennedi plateau in the northeast of the country. The geographic coordinates of the sites are given in Table 1 and supported by Fig. 1.

Tableau 1	:	Geographical	coordinates	of	the	sites.
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Site	Latitude	Longitude	Altitude
Amdjarass	16,1964 N	22,2774 E	752,23m
Fada	17,189 N	21,5847 E	742,36m



Fig 1 : Administrative Map of the sites.

#### Wind Data Description and Source

The data used in this work are essentially wind speeds from 01/01/1990 to 31/12/2019 (30 years). This data is provided by the data from NASA's MERRA-2 (Modern Era Reanalysis-assimilation for Research and Applications) atmospheric reanalysis. The measurements are taken per hour and at 10 m from the ground [12].

### Methodology

#### Weibull Probability Density Function

To evaluate the wind potential of the sites, the model used is the Weibull distribution which is commonly used, accepted and even recommended by previous works to express the distribution of wind speed because it gives a good agreement with the experimental data [13, 14]. The Weibull velocity distribution law is given by:

$$f(v) = \left(\frac{k}{c}\right) \times \left(\frac{v}{c}\right)^{k-1} \times exp\left(-\left(\frac{k}{c}\right)^k\right), (k \ge 0, v \ge 0 \ c \ge 1)$$
(1)

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

Where f(v) is the probability density function also called the frequency of occurrence of the wind speed, v is the wind speed (m/s). The parameters k (dimensionless) and c (m/s), called Weibull parameters characterize respectively the shape of the frequency distribution (shape parameter of the distribution) and the quality of the wind (scale parameter of the distribution). The determination of these parameters allows the knowledge of the wind distribution for a given site. They are determined by one of the most accurate and efficient methods called the EPF method [15, 16]. Equations (3) and (5) give the mathematical models used [17, 18]:

$$k = 1 + \frac{3.69}{(EPF)^2} \tag{3}$$

Where EPF is the factor energy obtained as a function of the instantaneous speed  $v_i$  by the relation:

$$EPF = \frac{\frac{1}{n}\sum_{i=1}^{n} vi^{3}}{\left(\frac{1}{n}\sum_{i=1}^{n} vi\right)^{3}}$$
(4)

$$c = \frac{\bar{\nu}}{\Gamma\left(1 + \frac{1}{k}\right)} \tag{5}$$

#### Extrapolation of wind speed

Wind speed measurements are generally made at 10 m altitude above the earth's surface. In order to have adequate speeds for the operation of wind turbines, the extrapolation of wind speed for different heights is obtained by the following relationship [1, 5]:

$$\nu(z_1) = \nu(z_0) \times \left(\frac{z_1}{z_0}\right)^{\alpha} \tag{6}$$

With  $v(z_0)$ , the wind speed at 10 m height;  $v(z_1)$ , the speed to be calculated at height  $z_1$ ;  $\alpha$ , the exponent of the power law, a function of the surface roughness given by the expression:

$$\alpha = \frac{0.37 - 0.088 \ln(v_{Z0})}{1 - 0.00881 \ln\left(\frac{Z_0}{10}\right)} \tag{7}$$

#### Extrapolation of the Weibull parameters

The Weibull parameters, k and c are given by expressions 8 and 9 [19]. From the calculation made at 10 m, we extrapolate the parameters according to the height where we want to install the wind turbines.

$$k_{Z} = \frac{k_{Z0}}{1 - 0.00881 \ln\left(\frac{Z}{10}\right)} \tag{8}$$

$$c_z = c_{z0} \times \left(\frac{z}{z_0}\right)^n \tag{9}$$

Where 
$$n = (0.37 - 0.088 \ln(c_{z0}))$$
 (10)

Z is the height at which the turbines will be installed,  $k_z$  and  $c_z$  the corresponding parameters.

#### Evaluation of the wind power density

It is an important characteristic of the wind which allows the estimation of the recoverable power on the studied site.

The power of wind (P(v)) can be estimated using equation (11) [20].

$$P(v) = \frac{1}{2}\rho A v^3 \quad (W) \tag{11}$$

The wind power density represents the amount of energy produced by the wind per unit area. It is given by expression [2, 15]:

$$\frac{P(v)}{A} = \frac{1}{2}\rho \int_0^{+\infty} V^3 f(V) dv = \frac{1}{2}\rho c^3 \Gamma(x)$$
(12)

With

$$x = 1 + \frac{3}{k}$$

(13)

where:

 $\rho$  = air density at the site;

A = swept area of the rotor blades  $(m^2)$ 

 $\Gamma$  is a function characterizing the shape of the frequency distribution and the skewness of the velocity frequency distribution. It is given by [21]:

$$\Gamma(\mathbf{x}) = \left(\sqrt{2\pi x}\right) (x^{x-1}) (e^{-x}) \left(1 + \frac{1}{12}x + \frac{1}{288}x^2 - \frac{139}{51840}x^3 + \cdots\right)$$
(14)

The air density (in kilograms per cubic meter) at a given site is computed as the mass of a quantity of air (in kg) divided by its volume (in cubic meter). It depends on elevation above

sea level and can be computed using Equation (15) [22,23].

$$\rho = \rho_0 - 1.194.\,10^{-4} H_m \tag{15}$$

The mean energy density over a period of time T is expressed as equation:

$$E_D = \frac{P(V)}{A}T = \frac{1}{2}\rho c^3 \Gamma(x)T$$
(16)

### Wind recoverable power density

To evaluate the recoverable wind power, we use the Betz coefficient recommended by several previous works. The expression of the recoverable wind power is given by [24, 25]:

$$Pr = \frac{1}{2}\rho C_p A c^3 \Gamma(x) \quad (W) \tag{17}$$

With the Betz coefficient 
$$C_p = \frac{16}{27}$$
 (18)

### Output power of the Wind turbine

The output power of the wind turbine is calculated using the equation [1, 26]:

$$P_{u} = \begin{cases} 0 & (v < v_{start}) \\ a + bv^{k} & (v_{start} \le v \le v_{rat}) \\ P_{n} & (v_{rat} \le v \le v_{stop}) \\ 0 & (v_{stop} < v) \end{cases}$$
(19)

With 
$$a = \frac{P_n V_{star}^k}{V_{start}^k - V_{rat}^k}$$
 and  $b = \frac{P_n}{V_{rat}^k - V_{start}^k}$  (20)

Where: V<sub>start</sub> is starting speed, V<sub>rat</sub> is rated speed, V<sub>stop</sub> is machine stop speed and P<sub>n</sub> is nominal power.

Electrical output power average (Pel) is given by expressions [26]:

$$P_{el} = \int_0^\infty P_u f(v, k, c) dv \tag{21}$$

Where  $P_{ij} = (a + b^k) + P_{ij}$ 

Where 
$$P_u = (a + b^k) + P_n$$
 (22)

and so 
$$P_{el} = \int_{V_{start}}^{V_{rat}} (a+b^k) f(v,k,c) dv + \int_{V_{rat}}^{V_{stop}} P_n f(v,k,c) dv$$
 (23)

$$P_{el} = P_n. FC \tag{24}$$

FC is the capacity factor given by equation:

$$FC = \frac{exp\left(-\left(\frac{V_{start}}{C}\right)^{k}\right) - exp\left(-\left(\frac{V_{rat}}{C}\right)^{k}\right)}{\left(-\left(\frac{V_{start}}{C}\right)^{k}\right) - \left(-\left(\frac{V_{rat}}{C}\right)^{k}\right)} - exp\left(-\left(\frac{V_{stop}}{C}\right)^{k}\right)$$
(25)

#### Usable wind power

Considering aerogenerator efficiency  $\eta$ , usable wind power average Pu is given by equation [26]:

$$P_u = \eta P_{el} \tag{26}$$

#### 3. Results and discussion

#### Wind potential

Figure 2 presents the average annual variation of wind speed at 10m height over the period from 01/01/1990 to 31/12/2019 (30 years) in the two selected sites (Amdjarass and Fada). The monthly variation of wind speed for the two sites is presented in Figure 3. The analysis of the curves shows that over 30 years, the average annual speeds vary randomly between 4.7 m/s and 5.4 m/s over an average period of 2 years. Figure 3 shows that for the two sites, 8 months (October to May) are recorded with high average monthly velocities between 5.01 m/s and 6.31 m/s in Amdjarass and 4.92 m/s and 5.70 m/s in Fada. The 04 months of low velocities are recorded from June to September where the velocities vary from 3.211 m/s to 4.064 m/s in Amdjarass and from 3.504 m/s to 4.516 m/s in Fada.



Fig 2: Average annual variation of wind speed at 10m height over 30 years.





#### **Evaluation of Weibull parameters**

The Weibull parameters k and c, calculated at 10m height for both sites are in Table 2. From this table, we can see that the smallest value of the shape parameter k (k=2.47, September) is observed at Amdjarass and scale parameter c (c=3.67 m/s, August) at Fada. While the highs values of k (k=2.74) are observed at Amdjarass and Fada in December and July respectively. The highs values of c are observed in April at Amdjarass (c=6.68 m/s) and March at Fada (c=6.01 m/s).

		An	ndjaras	s	Fada					
	V	$\sigma(m/s)$	Ŀ	С	Р	V(m/s)	$\sigma(m/s)$	Ŀ	c	Р
Month	(m/s)	0 (11/3)	ĸ	(m/s)	(W/m <sup>2</sup> )	v (III/S)	0(11/5)	ĸ	(m/s)	(W/m <sup>2</sup> )
Jan.	5,82	0,51	2,72	6,54	111,89	5,28	0,60	2,68	5,93	83,55
Feb	5,69	0,54	2,72	6,41	104,56	5,32	0,59	2,68	5,99	85,46
Mar	5,56	0,55	2,69	6,27	97,56	5,35	0,56	2,68	6,01	86,92
Ap.	5,04	0,45	2,72	6,68	72,67	4,78	0,42	2,73	5,37	61,99
May	4,65	0,47	2,69	5,24	57,07	4,60	0,42	2,70	5,14	55,25
June	3,79	0,43	2,70	4,28	30,90	4,23	0,42	2,72	4,76	42,96
July	3,36	0,32	2,69	3,79	21,53	3,39	0,23	2,74	3,80	22,11
Aug	3,00	0,35	2,65	3,89	15,32	3,27	0,29	2,71	3,67	19,85
Sept.	3,74	0,68	2,47	4,23	29,69	4,13	0,67	2,54	4,65	39,98
Oct.	4,89	0,52	2,70	5,51	66,37	4,98	0,48	2,69	5,60	70,10
Nov.	5,30	0,38	2,73	5,97	84,50	4,89	0,36	2,73	5,50	66,37
Dec.	5,66	0,44	2,74	6,38	102,92	4,95	0,51	2,72	5,57	68,84

Table 2: Weibull parameters for each site (1990-2019) at a height of 10 m

#### Extrapolation of data at different heights

Figure 4 shows the extrapolation of the annual mean wind speed at different heights (10m, 20m, 30m, 40m, 50m and 100m). It can be seen that the annual variations in wind speed increase with height at both sites. This can guide the choice of height for production optimization.



Fig 4: Extrapolation of Amdjarass and Fada wind speeds at different heights.

The extrapolation of the Weibull parameters is presented in Tables 3 and 4. It can be seen that the values of k vary very little in the two sites.

In Amdjarass, the value of k goes from 2.47 in September at 10m, to 2.92 in December at 100m while c goes from 3.79 m/s at 10m in July, to 10.12 m/s at 100m in January.

In Fada, k goes from 2.54 in September at 10m, to 2.92 in July at 100m while c goes from 3.96 m/s at 10m in August, to 10.03 m/s at 100m in February.

The variation of c with height demonstrates the proportionality of c with the average wind speed.

Journal of Renewable Energies 25 (2022) 109-126

				E	Extrapo	lation of	of k					
	Jan	Feb	Mar	Ар	May	June	July	Aug	Sept	Oct	Nov	Dec
10m	2,72	2,72	2,69	2,72	2,69	2,70	2,69	2,65	2,47	2,70	2,73	2,74
20m	2,74	2,74	2,71	2,74	2,71	2,72	2,71	2,67	2,49	2,72	2,75	2,76
30m	2,76	2,76	2,73	2,76	2,73	2,74	2,73	2,69	2,51	2,74	2,77	2,78
<b>40m</b>	2,80	2,80	2,77	2,80	2,77	2,78	2,77	2,73	2,54	2,78	2,81	2,82
50m	2,84	2,84	2,81	2,84	2,81	2,82	2,81	2,76	2,58	2,82	2,85	2,86
100m	2,90	2,90	2,86	2,90	2,86	2,88	2,86	2,82	2,63	2,88	2,91	2,92
				F	Extrapo	lation	of c					
	Jan	Feb	Mar	Ар	May	June	July	Aug	Sept	Oct	Nov	Déc
10m	6,54	6,41	6,27	6,68	5,24	4,28	3,79	3,89	4,23	5,51	5,97	6,38
20m	7,54	7,40	7,24	7,69	6,12	5,06	4,52	4,63	5,01	6,42	6,92	7,36
30m	8,15	8,00	7,84	8,31	6,67	5,55	4,97	5,09	5,49	6,98	7,50	7,97
<b>40m</b>	8,59	8,44	8,28	8,76	7,07	5,91	5,31	5,43	5,85	7,39	7,93	8,41
50m	8,95	8,79	8,63	9,11	7,39	6,20	5,58	5,71	6,14	7,72	8,27	8,76
100m	10,12	9,95	9,78	10,29	8,45	7,17	6,49	6,63	7,10	8,80	9,39	9,92

Table 3: Extrapolation of k and c (Amdjarass)

Table 4: Extrapolation of k and c (Fada)

Extrapolation of k												
	Jan	Feb	Mar	Ар	May	June	July	Aug	Sept	Oct	Nov	Dec
10m	2,68	2,68	2,68	2,73	2,70	2,72	2,74	2,71	2,54	2,69	2,73	2,72
20m	2,70	2,70	2,70	2,75	2,72	2,74	2,76	2,73	2,56	2,71	2,75	2,74
30m	2,72	2,72	2,72	2,77	2,74	2,76	2,78	2,75	2,58	2,73	2,77	2,76
40m	2,76	2,76	2,76	2,81	2,78	2,80	2,82	2,79	2,61	2,77	2,81	2,80
50m	2,80	2,80	2,80	2,85	2,82	2,84	2,86	2,83	2,65	2,81	2,85	2,84
100m	2,85	2,85	2,85	2,91	2,88	2,90	2,92	2,89	2,70	2,86	2,91	2,90
				I	Extrapo	lation c	of c					
	Jan	Feb	Mar	Ар	May	June	July	Aug	Sept	Oct	Nov	Dec
10m	6,44	6,47	6,49	5,99	5,56	5,11	4,30	3,96	4,88	6,09	6,04	6,20
20m	7,43	7,46	7,48	6,94	6,48	5,98	5,08	4,71	5,72	7,05	6,99	7,17
30m	8,03	8,07	8,09	7,52	7,04	6,51	5,57	5,18	6,25	7,64	7,58	7,77
40m	8,48	8,52	8,53	7,95	7,45	6,91	5,93	5,52	6,63	8,07	8,01	8,20
50m	8,83	8,87	8,89	8,29	7,78	7,23	6,22	5,80	6,94	8,41	8,35	8,55
100m	9,99	10,03	10,05	9,42	8,87	8,28	7,19	6,74	7,97	9,55	9,48	9,69

## Evaluation of Power Density and Available Energy.

The wind power density and annual available energy are presented in Figure 5. The analysis of this figure shows that the power density and energy are much higher in Amdjarass than in Fada.

At a height of 10m, the maximum value of 111.89  $W/m^2$  of power density is observed in Amdjarass in January, while in Fada it is around 86.92  $W/m^2$  in March. The minimum values of 21.53  $W/m^2$  in July and 19.85  $W/m^2$  in August are both recorded respectively in Amdjarass and Fada.

We also note that both parameters increase consistently with height.

This result confirms the results of Soulouknga et al., (2016) (the Saharan zone has a high-



power density) [10].



### Monthly Wind Speed Distribution

The frequency distributions of monthly wind speeds for the two sites are represented by the curves in Figures 6 and 7.

Figure 6 shows that at Amdjarass, the average wind speed is between 2 and 6.5 m/s. The period of low wind speed from June to September is clearly observed. The speed range extends slightly to 12 m/s.

In Fada, the curves in Figure 7 show that the average wind speed also varies between 2 and 6.5 m/s. The period of low wind speed, July and August is clearly observed. The speed range extends weakly to 10 m/s.





Fig 6: Monthly Wind speed distribution curves in Amdjarass at 10m height and cumulative frequency.





Fig 7: Monthly Wind speed distribution curves in Fada at 10m height and cumulative frequency.

### Evaluation of the useful and usable power

Four choices of wind turbines allowed us to evaluate the useful and usable power in kW. The characteristics of the wind turbines are given in the table 5.

Characteristics	BONUS	Hyosung	Vergnet GEV	Vergnet GEV
Characteristics	300kW/33	(HS50-750kW)	MP 275/32	HP 1000/62
Rated power (kW)	300	750	275	1000
V <sub>start</sub> (m/s)	3	3,5	4	3
V <sub>stop</sub> (m/s)	25	25	30	25
V <sub>rate</sub> (m/s)	14	14,5	12	15
Rotor diameter (m)	33,4	50	32	62
Hub height (m)	30	50	60	70

Table 5: The characteristics of the wind turbines [1, 2, 27]

The performance of the 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 [1]. We can only speak of electricity production from wind turbines if the load factor is at least 25 % [21].

When the capacity factors of the aerogenerators are evaluated, only the Vergnet GEV MP 275/32 gives values of around 25.46% at Amdajars and 26.33% at Fada.

Figure 8 shows that when we apply the wind data to the wind turbines in Table 5, we observe that the wind turbine Vergnet GEV HP1000/62 gives an important useful power (Pel) in both sites. Among the four wind turbines, only BONUS 300kW/33 gives weak results. When the useful power (Pu) is evaluated, it can be seen in Fada that only the Bonus wind turbine provides low power (8.77 kW). The other three wind turbines provide the following powers: 25.03 kW for Hyosung (HS50-750kW), 23.39 kW for Vergnet GEV MP 275/32 and 24.56 kW for Vergnet GEV HP1000/62. In Amdjarass, we obtain 8.05kW with BONUS 300kW/33, 22.80kW with Hyosung (HS50-750kW), 22.62kW with Vergnet GEV MP 275/32 and 30.63kW with Vergnet GEV HP1000/62.



Fig 8: useful and usable power

### 4. Conclusion

The present work has made it possible to evaluate the wind energy potential of the two sites, Amdjarass and Fada, respectively the capitals of the provinces of East Ennedi and West Ennedi in Chad. This study shows the following:

- Over the 30 years of recordings at the two sites, the average annual wind speeds vary randomly between 4.7 m/s and 5.4 m/s over an average period of 2 years.
- There are eight (08) months from October to May with high average monthly wind speeds ranging from 4.89 m/s to 5.82 m/s in Amdjarass and ten (10) months from September to June with high average monthly wind speeds ranging from 4.13 m/s to 5.35 m/s in Fada.
- There are 4 months of low velocities from June to September where the velocities vary from 3.00 m/s 3.79 m/s in Amdjarass and two months in Fada where the wind speed is on average 3.33 m/s (July and August).
- The smallest value of the shape parameter k (k=2.47, September) is observed at Amdjarass and scale parameter c (c=3.67 m/s, August) at Fada. While the highs values of k (k=2.74) are observed at Amdjarass and Fada in December and July respectively.
- The highs values of c are observed in April at Amdjarass (c=6.68 m/s) and March at Fada (c=6.01 m/s).
- The maximum value of 111.89 W/m<sup>2</sup> of power density is observed in Amdjarass in January while in Fada, it is about 86.92 W/m<sup>2</sup> in March. The minimum values of 21.53 W/m<sup>2</sup> and 19.85 W/m<sup>2</sup> were recorded in July in Amdjarass and August in Fada respectively.
- The Vergnet GEP MP 275/33 aerogenerator is more efficient and better recommended for the two study sites.

### List of symbols

NASA: National Aeronautics and Space Administration

MERRA-2: Modern Era Reanalysis-Assimilation for Research and Applications

v: Monthly average wind speed m/s

P(v): Power density in  $W/m^2$ 

F(v): Weibull distribution function

E<sub>D</sub>: Energy produced in kWh

EPF: Energy of factor

б: Standard deviation of the wind speed distribution in m/s

ρ: Density of the area in Kg/m<sup>3</sup>
k: distribution shape parameter
c: frequency of occurrence of the wind speed in m/s
T: time in hours
FC: capacity factor
V<sub>start</sub>: Starting speed in m/s
V<sub>rate</sub>: Nominal speed in m/s
V<sub>stop</sub>: Stopping speed in m/s

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