Wind Resource Assessment in the City of N'djamena in Chad

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Received: 11.04.2016 Accepted: 10.06.2016

Abstract: The aim of this study is to evaluate the wind energy potential of the city of N'Djamena, and to evaluate of the annual energy produced at an altitude of 100 m by simulating wind data using the wind speeds data collected at N'Djamena airport's weather station for a twelve months period. In this perspective, we start with the description of the site through the determination of parameters related to the wind, the mathematical modeling of the frequency distribution of the wind: Weibull distribution and processing and numerical simulation of the actual wind data collected on a selected site of the city of N'Djamena. We then estimate its wind potential, the prediction of the electrical energy production and, determine the direction of the wind on the site. We conduct an analysis of wind turbulence considering different factors such as surrounding obstacles near the measurement tower of the airport in N'Djamena, topography, roughness of the site and choice of wind mill. As a result, the installation of a wind farm of 10 wind mill Vestas V80 / 1.8 MW at 100 meters would produce 50,420 MWh of energy.

Keywords: Wind energy - energy transformation – Wasp - simulation –N'Djamena.

1. Introduction

The negative effects of fossil fuels on the environment have led scientists to consider the possibility of using renewable energy to generate electricity. Among the many clean or green power resources, there is wind power, which has experienced very rapid growth over the past two decades. Indeed, major technological advances have been made, which has reduced the cost of producing wind-generated electricity. Today, the share of renewable energy accounts for only about 20.2% of global electricity production [1].

Because of the pollution and the production of greenhouse gases generated by the use of fossil fuel, wind power, which is a reliable and promising renewable energy, has been growing interest due to its almost inexhaustible and non-polluting characteristics [2, 3]. The conversion of wind energy for electricity generation or pumping could thus help to reduce a number of problems of African people.

The main objective of this article is to assess the wind resource available in the city of Ndjamena as to contribute to the development of the exploitation of domestic energy resources offered by the wind potential of the Chad.

The present manuscript is organized as follow: in the first time, the description of the study area is present; after the material and methods used are showed; then the results are presented; finally the last section summarizes work and gives perspectives for future continuation.

2. Description of the Town of N'Djamena with Geographical Data

N'Djamena is the capital city of the Republic of Chad, situated at an elevation of 297 m above the sea, in the Central West region of the country, at the confluence of Chari and Logone rivers. Located on the right bank of Char river. The town is connected to the left bank of the Chari by two bridges: a single track bridge (the Chagoua bridge), and a double-track bridge (the Taiwan bridge). Cameroonian town of Kousseri is located about 10 km from N'Djamena, on the left bank of Logone river, which marks the border and is accessible by the Ngueli bridge. The weather station is located at the airport Ndjamena and its measuring mast for wind data has the following geographical coordinates: longitude 15 ° 12 ° latitude and 01'48.49"E 07'36.24N.

Fig. 1. Measuring mast for wind data at n'djamena airport

3. Material and Methods

3.1. Material

3.1.1. Golden software

Golden Software is a specialized tool for the development of the topographic map. It embeds a grid-based mapping program which interpolates irregularly spaced XYZ data into a regularly spaced grid. The resolution of our map is 200 m, resulting in 4500 data points processed with the databases in Excel software. The grid is used to produce different types of maps including cutting, vector, image, shaded relief, 3D surface and wireframe 3D charts. Generally, gridding and mapping options are available and can produce the maps that best fit our data.

3.1.2. Wasp

WAsP (Wind Atlas Analysis and Application Program) is a digital tool developed in 1987 by the Atmospheric Physics Department of the Danish RISO National Laboratory. This computer code benefits of a positive feedback from users; it is the reference software of the wind industry for the analysis of wind resources, the establishment of wind atlas, and the choice of installing wind turbines on a site. WAsP was used to create our different entry files.

3.2. Mathematical modeling

3.2.1. Modeling of the distribution of frequencies of the wind

3.2.1.1. The Weibull Distribution

The Weibull distribution is a special case of the Pearson distribution [4]. 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.

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

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.

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

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

$$V_m = \int_0^{\infty} v \times f(v)\, dv \quad (3)$$

The distribution of Weibull proves to be suitable for the description of the statistical properties of the wind [5, 6, 7].

3.2.1.2. 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 [4, 8, 7]. Since wind data are available in the format of frequency distribution, the recommended method is the modified maximum likelihood method [7]. Weibull parameters are determined using equations (4) and (5):

$$K = \left(\frac{\sum_{i=1}^{n} V_i^k \times Ln(v_i) \times f(v_i)}{\sum_{i=1}^{n} V_i^k \times f(v_i)} - \frac{\sum_{i=1}^{n} Ln(v_i) \times f(v_i)}{F(v \geq 0)}\right)^{-1} \quad (4)$$

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

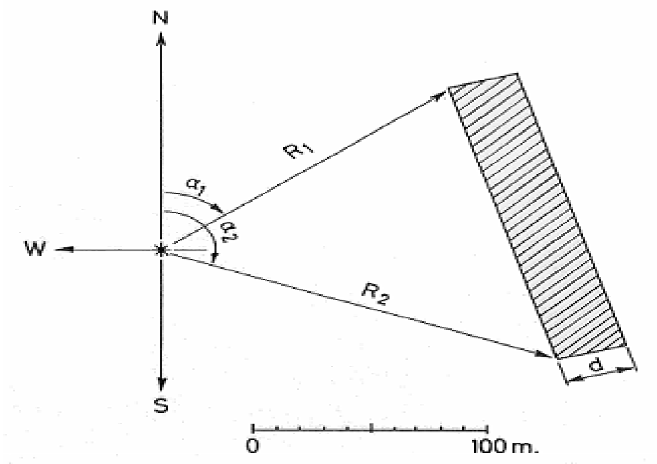
Where Vi is the midpoint of the interval of speeds i, n the number of intervals, f (Vi) the frequency for which the wind speed falls in the interval i, F (v = 0) the probability that the wind speed is greater than or equal to zero.

Equation (4) is solved numerically by successive iterations until the convergence of the value of K using a code written in FORTRAN 90. The computations are initialized with K = 2. After convergence, equation (5) is then explicitly resolved using the value of K to find that of C.

3.2.2. Modeling of an obstacle

Near an obstacle, such as a building, the wind is strongly influenced. The mast of the anemometer to the airport is surrounded by buildings and trees, which influences the data-gathering. The exploitation of those requires taking into account the various obstacles of the site.

We model the obstacle as follows:



For an observer located at the position of the anemometer and watching a given obstacle, we have:

- α1, angle (°) between the geographical north and the first corner;

- R1, radial distance (m) to the first corner;

-α2, angle (°) between the geographical north and the second corner;

- R2: radial distance (m) to the second corner;

- h, height of the obstacle in (m);

- d, depth of the obstacle in (m);

- P, estimates of the porosity of the obstacle.

Number located between (0 -0.1 -0.2 - -0.9 -1).

The angles are measured clockwise from 0 ° (North) to 360 °.

Roughness intuitively defines obstacles seen from a distance, or a set of very small obstacles considered at wind scale. Data covering this concept of roughness are empirical and there is no sufficiently precise formula to represent all the moving and lively variety of grass, trees growing and cities built [9, 10].

The roughness of land is often parameterized by a length scale called Z_o roughness length. A simple empirical relation between the elements of roughness and roughness length was formulated by Lettau [11].

$$Z_0 = 0.5\,(h \times S)/A_H \quad (6)$$

Where h is the height of the roughness element (m), S, its cross-section facing he wind (m^2) and A_H, the average horizontal surface (m^2) defining the distribution of roughness elements.

3.2.3. Density of wind energy

The available power in a wind flow of velocity v is obtained from the relation:

$$P = \frac{1}{2} \rho \times A \times V^3 \quad (7)$$

Where ρ is the air density (kg/m3), and A, the scanned surface (m2) of the blade of the wind turbine. Expressing this power per area unit, we have:

$$P_v = \frac{1}{2} \rho \times V^3 \quad (8)$$

The time fraction for which this velocity v prevailing in the system is given by the probability distribution function f (v). Thus, the energy contributed by v, per time unit and per area unit, is $P_{(v)} \times f(v)$. So the total energy contributed by all possible speeds in the wind regime, available by area unit and time unit (Energy Density ED) can be expressed as follows [4, 12, 13]:

$$E_D = \int_0^\infty P_v \times f(v) \times d_v \quad (9)$$

3.2.4. Statistical data processing

a- Calculating the arithmetic velocity mean

$$\overline{V} = \frac{1}{n} \times \sum_{i=1}^{n} Vi \quad (10)$$

b- Calculating arithmetic weighted velocity mean

$$\langle P \rangle = \sum_{i=1}^{n} Vi \times f(Vi) \quad (11)$$

c- Calculating of the average power per area unit (energy density)

$$\langle P \rangle = \frac{\sum_{i=1}^{n} P(v_i) \times f(v_i)}{\sum_{i=1}^{n} f(v_i)};$$

$$P(v_i) = \frac{1}{2} \times \rho \times v_i^3 \text{ alors}$$

$$\langle P \rangle = \frac{1}{2} \times \frac{\sum_{i=1}^{n} v_i^3 \times f(v_i)}{\sum_{i=1}^{n} f(v_i)} \quad (12)$$

4. Results of Numerical Simulation

4.1. Modeling obstacles of the site of collection

Some of the major obstacles on N'Djamena airport site were modeled using the software WAsP (Wind Atlas Analysis and Application Program) in order to take into account their influences on data collection. Buildings are in black and trees in blue.

a- Modeled obstacles b- Aerial view of the site

Fig. 2. Obstacles surrounding the data collection site

4.2. Wind potential of the airport site at the height of measurement

Measurements of wind velocity were grouped into intervals and associated with their frequencies on the site.

This mode of representation gives us information on the number of hours for which the wind velocity is within a specific range. Those from N'Djamena airport site are presented in table 1.

Table 1 Frequency distribution of wind speed (m/s)

Speeds	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
Frequencies	6.7	13.5	21.2	19.7	13.1	9.4	6.3	3.9	2.4	1.4
Speeds	10-11	11-12	12-13	13-14	14-15	-	-	-	-	-
Frequencies	0.9	0.6	0.5	0.3	0.1					

Weibull parameters for this distribution are: C = 4.2 m / s and K = 1.44. The wind rose shows the distribution of recorded wind directions on the site. It allows us to know the prevailing wind direction. The atmospheric circulation at ground level is mainly driven by the North East wind direction.

Frequency analysis of the wind speed highlights the predominant speed classes. Therefore, and according to the characteristics of the wind turbines on the market, one can select those that provide the best performance. We group the distribution of wind speed by classes, the frequency being expressed directly in percentage; it allows us to know the probability that a speed value is not exceeded.

Figure 3 shows a predominance of speed-class of 2-3 m/s, which represents 21.2% of cases, followed by speed-class 3-4 m/s with 19.7%). Speed-class 0-1 m/s is 6.7% while speed-class 1-2 m/s accounts for 13.5%.

Knowing these parameters, it is then possible to plot on the same graph of the probability density function and the speed frequency histogram.

Annual data of the frequency distribution of wind speed gives the following information:

– Maximum wind speed on the site = 19 m/s

– Annual speed = 4 m/s

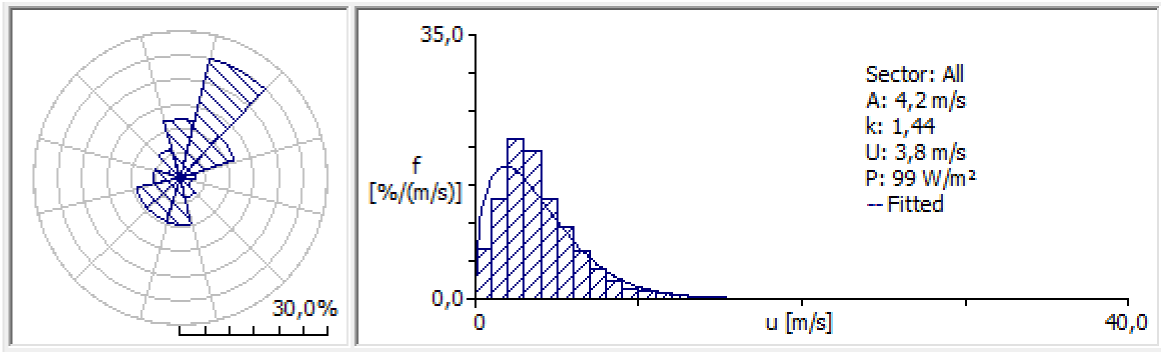


Fig. 3. Frequency histogram and wind rose of wind speeds modeled with Weibull distribution using the computer code WAsP (Wind Atlas Analysis and Application Program).

From Weibull distribution.

- Mean velocity = 3,9 m/s

- Density of energy = 99 W/m^2

4.3. Probability Density Function

Equation (1) describes the parameters of the Weibull probability density function of wind speed; they follow the shape of a 1/2 Gaussian and are the same as those of the CDF. The blue curve represents the PDF and the black histogram represents the data.

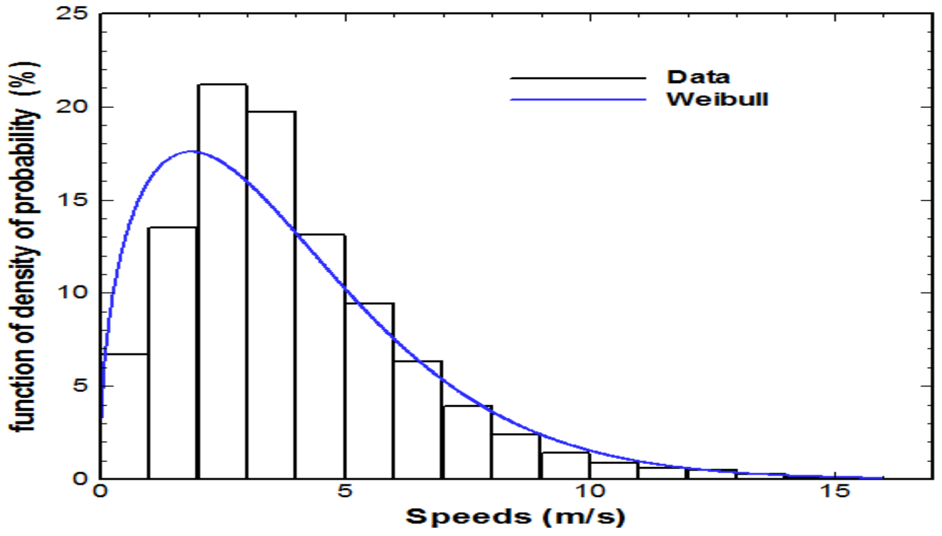


Fig. 4. Histogram of wind speed frequencies modeled by the distribution of Weibull. Calculations were carried out using a code written in FORTRAN 90.

4.4. Cumulative distribution function

Parameters of the cumulative distribution function (CDF) of wind speed are the same as those used for the PDF. The curve represents the CDF while the histogram represents the data. Another observation shows a similarity between the evolution of the histogram and the shape of the CDF curve.

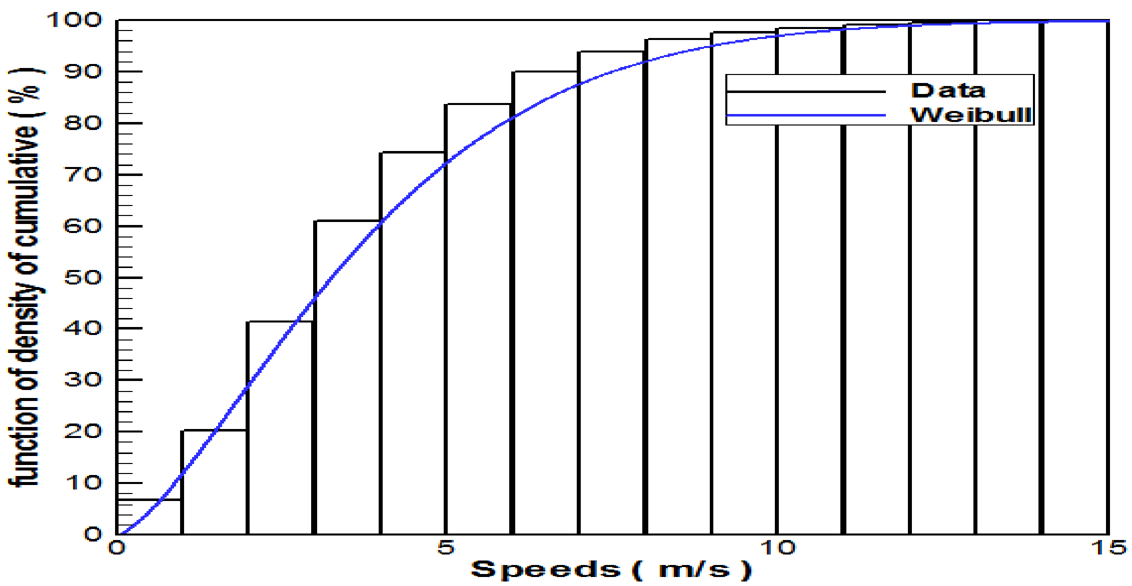


Fig. 5. Histogram of cumulative frequencies of wind speed modeled by the distribution of Weibull. Calculations were carried out using a code written in FORTRAN 90.

4.5. Wind atlas of the city of N'Djamena

Wind characteristics are specified for a number of roughness classes chosen as reference, and heights taken with respect to ground level. These characteristics are independent of the location and therefore describe the wind behavior all over the site.

Table 2. Wind Atlas.

		R-Class 0 0.000 m	R-Class 1 0.030 m	R-Class 2 0.100 m	R-Class 3 0.400 m	R-Class 4 1.500 m
Height 1 Z = 10 m	U (m/s) P (W/m^2)	7.40 748	5.49 319	4.80 209	3.79 101	2.52 29
Height 2 Z = 25 m	U (m/s) P (W/m^2)	8.07 952	6.46 493	5.85 361	4.93 213	3.78 96
Height 3 Z = 50 m	U (m/s) P (W/m^2)	8.61 1126	7.31 665	6.73 515	5.87 340	4.79 186
Height 4 Z = 100 m	U (m/s) P (W/m^2)	9.21 1363	8.35 898	7.78 725	6.94 515	5.90 320
Height 5 Z = 200 m	U (m/s) P (W/m^2)	9.93 1707	9.74 1348	9.12 1100	8.24 811	7.17 542

In this table, the wind energy densities show high values for the class 0,000 m because wind can flow there without facing any obstacle

4.6. Extrapolation of wind speed at 100 m height

The mast of the selected wind mill has a height of 100 m who is the height of implantation of aero-generator. This height is greater than that of the mast used for data collection (10 m). The vertical extrapolation model [14, 15] of the wind speed measurements from 10 m to the height of the turbine axis becomes imperative, and therefore results in a variation of the wind distribution. The wind climate characteristics are summarized in Figure below. For all sectors of this site, the average wind speed (Eq. 3) is Vm = 7.16 m/s with an energy density (Eq. 9) ED = 539 W/m^2. Those equations were resolute with a Fortran code.

Table 3. Wind characteristics and speed frequency distributions at 100 m and by sector

sector	Angle (°)	Frequency (%)	Weibull (m/s)	Weibull K -	Mean velocity (m/s)	Density of energy (W/m^2)
1	0	12.9	6.1	2.04	5.34	183
2	30	24.2	7.9	1.87	7.02	435
3	60	11.2	13.5	2.24	11.97	1803
4	90	3.3	12.6	1.77	11.17	1862
5	120	2.3	9.3	1.42	8.48	1099
6	150	4.5	8.4	2.20	7.47	447
7	180	9	8.9	2.16	7.90	535
8	210	9.2	7.7	2.49	7.87	315
9	240	9.3	5.5	2.87	4.86	101

10	270	5.4	5.3	2.64	5.70	100
11	300	2.7	5	2.37	4.43	87
12	330	6.3	5 .5	2.10	4.86	128

4.7. Prediction of produced electrical energy

The annual production of electrical energy is calculated for 12 sectors of the wind rose. Taking into account the characteristics of the wind turbine that we have chosen, the annual energy for all combined sectors is 5042 MWh that is an average power output of 573 KW.

Table 4. Wind power density and annual electrical power produced by sector.

	Angle (°)	Density (W/m^2)	Production annuelle (MWh)
1	0	183	181
8	30	435	911
3	60	1803	119
4	90	1862	243
5	120	1089	145
6	150	447	265
7	180	535	585
8	210	315	454
9	240	101	152
10	270	100	86
11	300	87	37
12	330	128	108

Sectors 2 and 3 are the largest contributors of energy with 25.7% and 23.6% respectively; meaning 911 MWh and 119 MWh. Then there are sectors 1, 4 and 12 respectively with 7.6%, 5.9% and 2.6%; meaning 181 MWh, 243 MWh and 108 MWh. So the winds are dominant in the northeast direction. With a planned number of 10 installed wind turbines, the expected annual wind energy on the site is 50420 MWh yielding an average power output 5.73 MW.

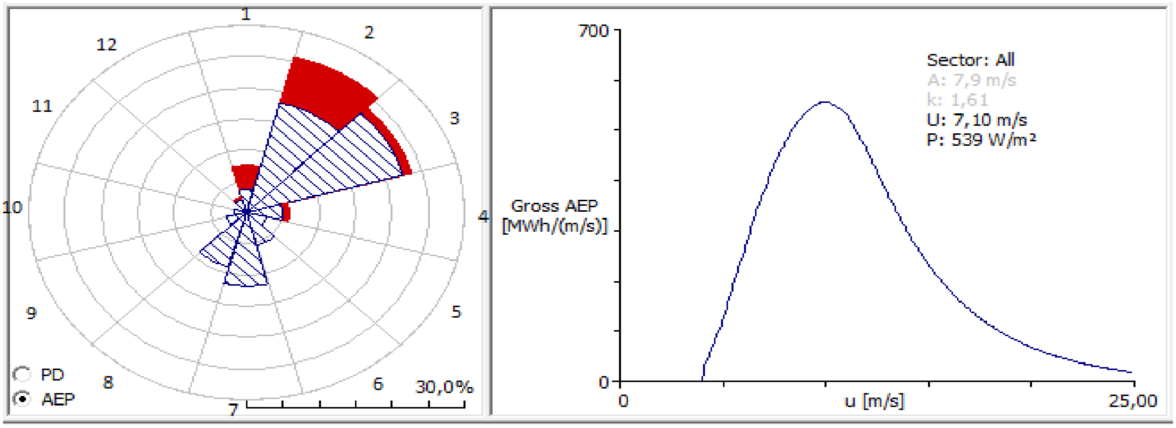


Fig. 6. Produced electrical energy estimated by sector

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4.8. Orientation of wind mills

The observation and analysis of wind statistics show that there is predominance of wind in the northeast direction. The highest is recorded in sector 2. This annual survey enables to opt for the Northeast direction, specifically an inclination to the north of a geometric angle varying between the first and the fourth sector (between 15 ° and 75 °) with a preference for sector 2 (15 ° and 45 °) where the winds are dominant.

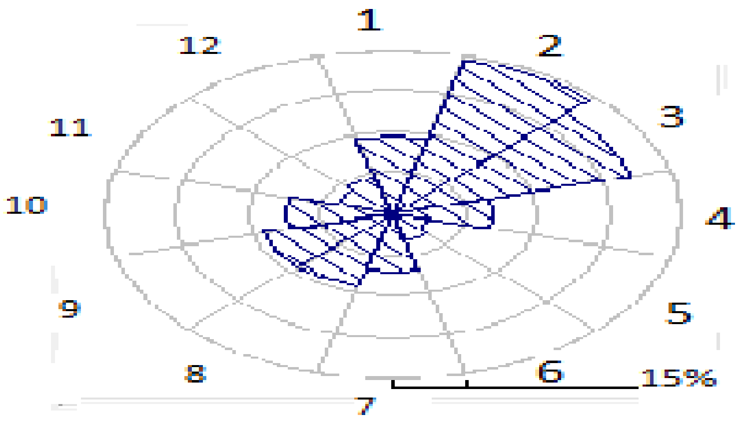


Fig. 7. Wind rose of the site of N'Djamena

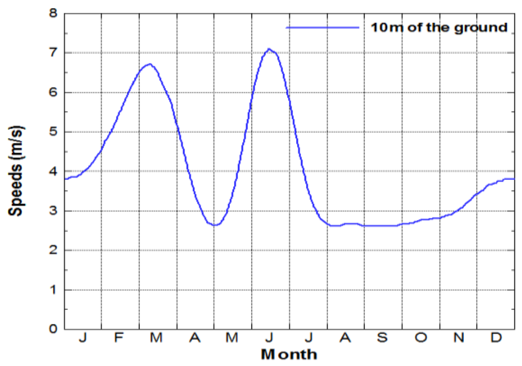
The use of this figure allows during the implantation of wind, the position in the direction of the prevailing wind (Sector 2 and 3), if there is not the possibility of installing a wind follower, which for most of the time is itself energy consumer.

4.9. Turbulence analysis

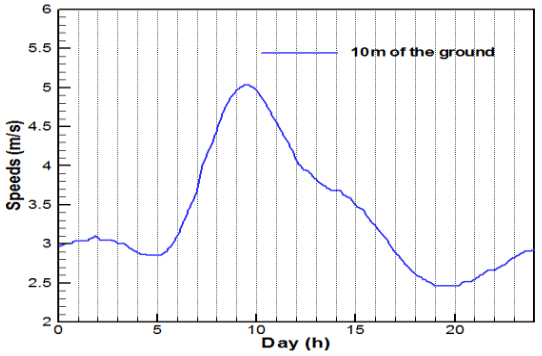
The average variations over the year are sometimes used to define the wind or winds (sometimes quite different) who regularly visit the site. Most common in Ndjamena are harmatan north and towards the center part and, the Monsoon towards the south.

This also allows you to see, depending on desired uses of the wind produced electricity and other forms of turbines generated electrical power, if this production is (or is not), on average, in line with electricity consumers needs and other forms of electricity production. One could partly explain these variations by the changes in roughness due to changing seasons. Observing the average daily variations of wind speeds on the plot shows that the wind speed is very low between 7 pm and 12 pm Universal Time.

The study of monthly variations indicates periods of permanent electricity production at the station. Variations in wind speed show two (2) peaks in March and in June. These months are thus expected to be the most productive.



a- Monthly speed variations

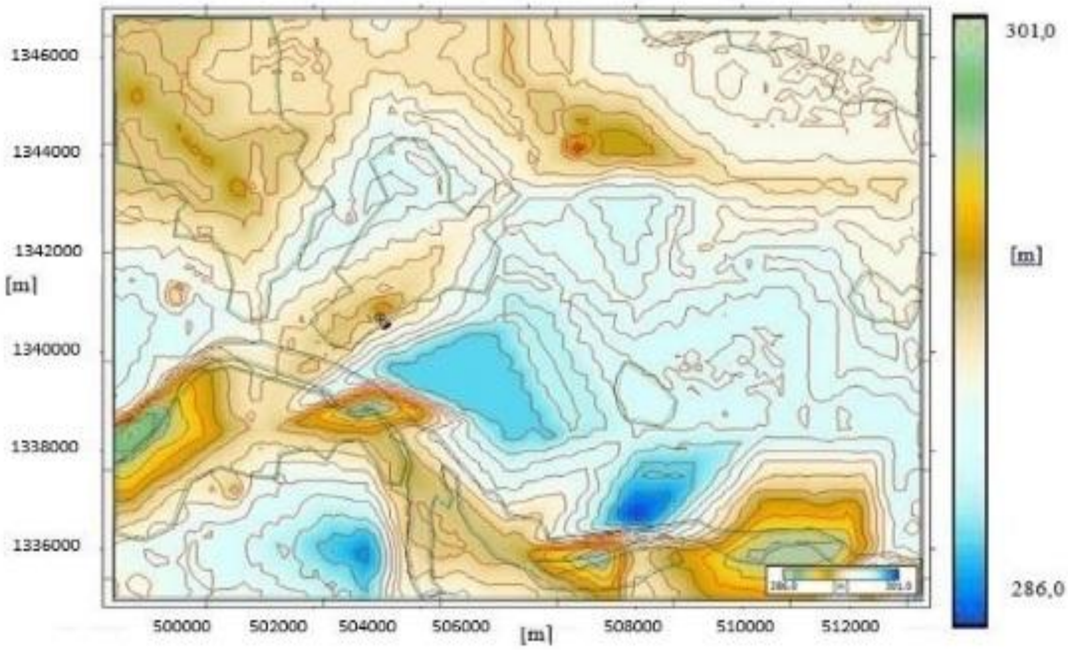


b- Daily speed variations

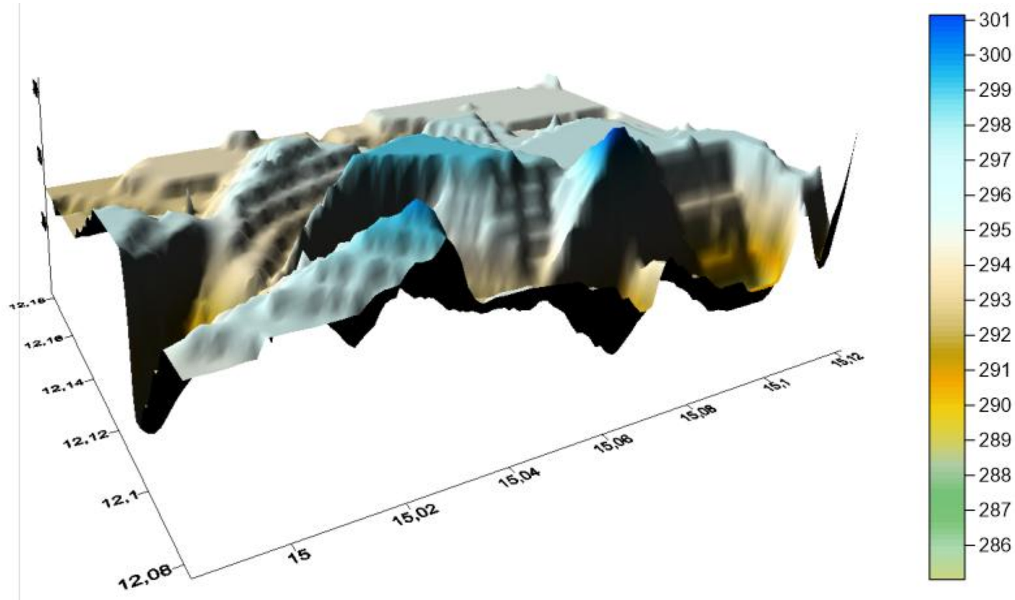
Fig. 8. Average speed variations over the year (a) and in one day (b)

4.10. Topographic map in 2D and 3D of N'Djamena city

According to the topographic map in 2D and 3D we observe that the gap between the lowest point and the highest relief does not exceed 15 m; this may indicate that the site is a relatively flat terrain. Hollow areas are the water bed of Logone-Chari river.



a- topography in 2D



b-topography in 3D

Fig. 9. Topographic chart in 2D and 3D of the town of N'Djamena

4.11. Annual Wind map in N'Djamena.

One notices in this topographic chart three dominant colors:

- it restricted parking zone, which represents the zone having the weakest potential wind mill with a speed of 6.30 m/s for a latitude of 512000 m and a longitude of 1346000 m;

- The green zone represents the average zone speed;

- The red zone, which represents the zone having the strongest potential wind mill with a speed of 7.16 m/s for latitude of 504000 m and a longitude of 1344000 m.

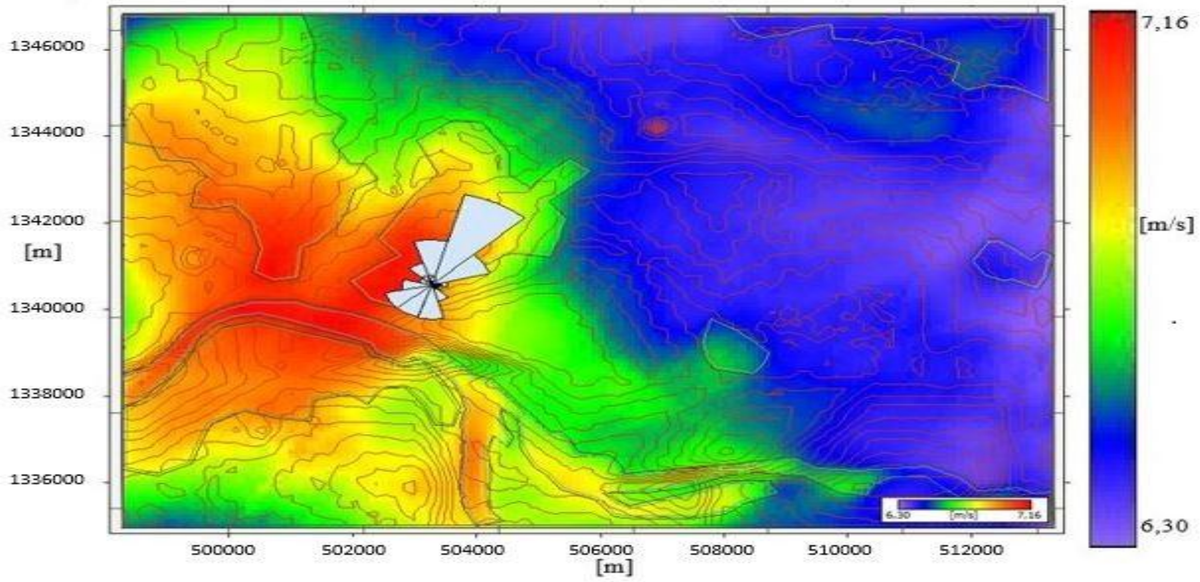


Fig. 10. Annual wind map of the city of N'Djamena.

4.12. The predicted annual wind energy production in N'Djamena

We note in this topographic map three dominant colors:

• The blue areas represent the zones with the lowest wind potential with a speed of 6.30 m/s to 512000 m latitude and longitude of 1346000m;

• The green areas represent the medium speed zones;

• The red areas, which represent zones with the highest wind potential with a speed of 7.16 m/s to 504000 m latitude and longitude of 1344000m.

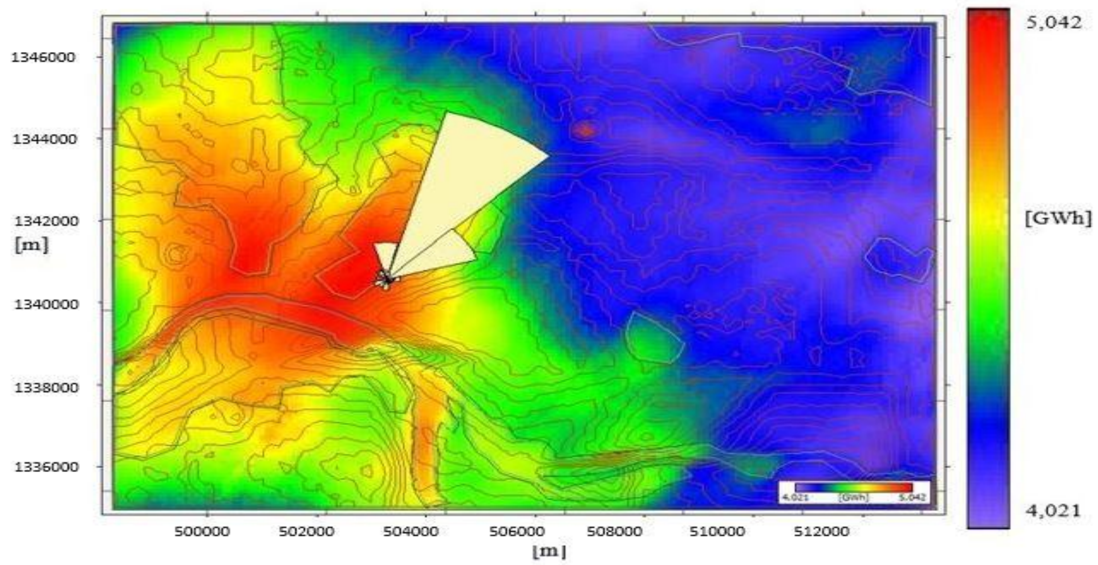


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Fig. 11. Annual wind power production in N'Djamena

4.13. Choice of the aerogenerator

The production power of a wind turbine varies with the wind on the rotor. Indeed, the power output curve increases with wind speed. The choice of a wind turbine relies on criteria such as: boot speed, mast height, the maximum power output and the air density. The wind turbine, which we chose for our site, is the Vestas V80 model builder.

Table 5. Vestas V80 wind turbine features

Charateristics	Specifications
Boot speed	3.5m/s
Mast height	100 m
Diameter of rotor	30 m
Maximum power	1.8 MW
Density	1.225 Kg/m^3
Manufacturer	Vestas. Wind system

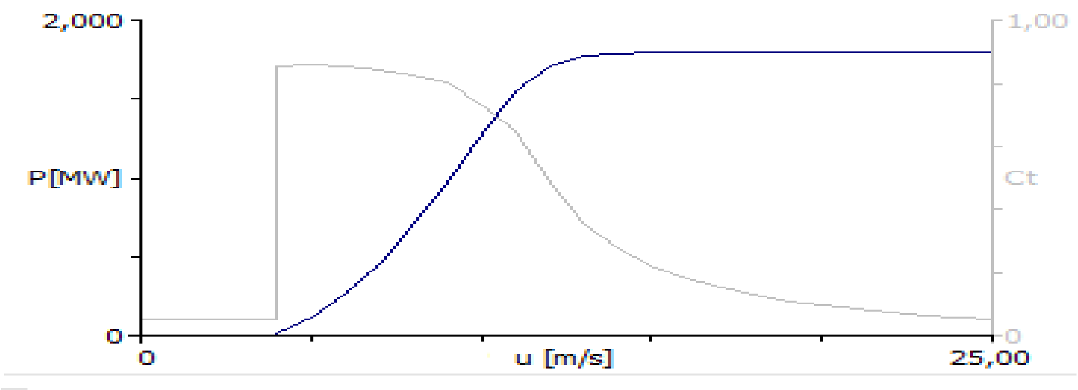

Fig. 12. Power curve of the Vestas V80 wind turbine

4.14. An estimate of wind power production of a wind park at 100 m

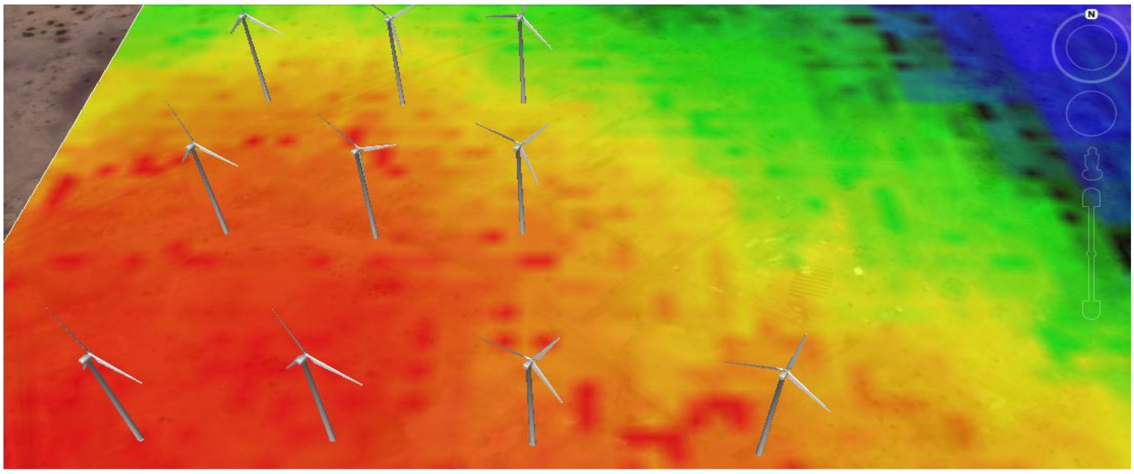

Fig. 13. Wind turbines on a site of the city of Ndjamena

A wind farm site of the city of N'Djamena with 10 wind turbines would generate 50.420 GWh a year for an extrapolation of 100 m whose detailed coordinates are in Table 6

Table 6. Coordinates for the different turbines for the town of N'Djamena

Description of the site	Lat (m)	Long (m)	rise (m)	Speed (m/s)	AEP (GWh)	Losses of Wake
Site of turbine 01	503056.4	1341420	293.7	7.16	5.042	4.11
Site of turbine 02	503314.4	1341425	293.9	7.06	4.951	11.73
Site of turbine 03	503011.4	1341678	294.4	7.09	4.972	16.09
Site of turbine 04	503247.1	1341678	294.2	7.06	4.941	14.31
Site of turbine 05	502961.0	1341947	295.1	7.05	4.910	6.88
Site of turbine 06	503146.1	1341930	294.7	7.04	4.911	11.47
Site of turbine 07	503507.9	1342061	294.6	6.97	4.845	8.88
Site of turbine 08	503583.7	1341531	293.6	7.03	4.911	9.1
Site of turbine 09	503810.9	1342136	294.7	6.93	4.803	5.83
Site of turbine 10	503848.7	1341644	293.7	6.95	4.822	5.12

These different turbines are in the northeast direction of the city of Ndjamena and specifically in Goudji charafa and lamadji neighborhoods. Table 7 shows the statistics of the overall characteristics of the park / year in the city of Ndjamena.

Table 7. Annual production of the site

Variables	Total	Average	Minimum	Maximum
Total AEP (GWh)	49.054	4.905	4.803	4.988
AEP Net (GWh)	43.957	4.396	4.172	4.576
Relative errors (%)	10.39	--------	5.12	16.09
Mean velocities (m/s)	------------	7.03	6.93	7.10
Density of power (W/m^2)	-------------	525	500	544

5. Conclusion and Perspectives

This work consists of the numerical simulation of wind data for electricity production for the case of the city of N'Djamena. The estimated wind potential of the city of N'Djamena, bounded by latitudes 12 ° 07 '36 .24"N and longitudes 15 ° 01'48.49 E is assessed using WAsP software.

Weibull parameters characterizing the site are in the range 4.2 m/s for the scale factor and 1.44 for the form factor, which means that the wind speed varies on the Ndjamena airport site with winds moving predominantly around the Northeast direction according the wind rose.

The wind potential of the site at 100 m height has an average speed of 7.16 m/s and a power density of 539 W/m2 for the privileged sector (sector 2), so without associating a follower wind, wind turbines at their location, for the purpose of optimizing the energy production, must follow this direction. Although the data are collected 10 m above the ground, the installation of a wind farm of 10 Vestas V80 /1.8 MW wind turbines at 100 meters, would produce 50.420 MWh of energy.

This demonstrates that the amount of wind produced in this area is highly suitable for use in aero-generators.

Finally, the measured parameter values and those calculated statistically are very close approximation of values obtained from mathematical modeling using Weibull distribution, which validates the use of this model for purposes of prediction.

Further and future work would concern the introduction in our model and numerical simulations of the interactions between wind turbines also called wake effect and turbulence of the wind turbine blade in order to provide an accurate estimate of the energy production of a wind mill park.

Acknowledgements

The authors warmly ASECNA N'Djamena for weather data and Risø National Laboratory, Department of Wind Energy, at Technical University of Denmark. The reviewers are also thanked for their constructive comments.
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Nomenclature:

$\boldsymbol{V}$: Speed of the wind, m/s

$\boldsymbol{C}$: Scale factor, m/s

$\boldsymbol{Z_0}$: Length of roughness, m

$\boldsymbol{Z}$: Height of measurement, m

$\boldsymbol{V_{max}}$: Maximum speed of the site, m/s

$\boldsymbol{K}$: Factor of form of the curve

$\boldsymbol{n}$: Number of interval speed, m/s

$\boldsymbol{\rho}$: Density of the air, $\mathrm{Kg/m^3}$

$\boldsymbol{h}$: Height of the element of roughness, m

$\mathbf{f}\ (\boldsymbol{V})$: Function of density of probability

$\bar{\boldsymbol{V}}$: Arithmetic mean velocity of the wind, m/s

$\mathbf{P_v}$: Power per unit of area, W/m^2

$\boldsymbol{P}$: Power in a flood of wind speed v, w

$\boldsymbol{V}$: Speed of the wind, m/s

$\boldsymbol{F}\ (\mathbf{V})$: Function of cumulative distribution speed

$\langle \boldsymbol{V} \rangle$: Arithmetic balanced mean velocity of the wind, m/s

$\langle \mathbf{P} \rangle$ = Density of wind energy obtained starting from measurements , W/m^2

$\boldsymbol{A_H}$

: Surface of horizontal surface delimiting the repartion of the element of roughness, m^2

$\mathbf{S}$: Surface of the cross section of the obstacle vis − a − vis the wind, m^2

$\boldsymbol{E_D}$: *Density of wind energy calculated by means of the distribution*, W/m^2

$\boldsymbol{A}$: *Surface of the swept surface of the blade of the wind mill*, m^2

$\boldsymbol{R-classe}$: *Roughness class (class of roughness)*, m

$\boldsymbol{V_m}$: Mean velocity of the wind by means of the distribution of Weibull, W/m^2

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