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Technical-economic Analysis of Eolien Potential and Application to Date Palm at the Two Sites of the Republic of Chad

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Abstract: The aim of this work was to make a technical and economic assessment of the wind potential of two cities in the Republic of Chad. With this in mind, start with the different parameters related to wind, such as mathematical modeling of wind frequency distribution: weibull distribution and then the processing and numerical simulation of wind data collected for 24 months every 30 minutes, in order to provide predictions at the two sites in Chad. Then evaluate its wind potential, its prediction of the electrical energy produced while taking into account the obstacles surrounding the collection site in order to map the resource available in favorable areas. Weibull's parameters for the site are 4.2 m/s and 1.44 at N'Djamena, while at Faya 6.2 m/s and 1.69 respectively, which means that wind speeds vary at both sites. Roughness, wind profile and topography determine the location of wind turbines. Electricity is generated once the wind turbine is installed. It appears that at 100 m in height, the average wind speed and wind energy density are 7.40 m/s and 746 W/m^2 respectively in N'Djamena, while in Faya at identified favourable sites, they are 16.4 m/s and 4414 W/m^2 respectively. Annual Net energy production is 5.068 GWh in N'Djamena, while Faya is 9.316 GWh. The roto-dynamic pump at an annual rate of 4.577 m^3/h. The expected volume of water is 20,417 m^3, which would serve approximately 1.655 people per year. For a date palm crop, the annual water need is in the range of 15.000 to 20.000l/ha. KWh's costs for the N'Djamena and Faya wind power plants are 0.097$/KWh and 0.067 $/KWh, respectively.

Keywords: Wind Turbine, Energy Conversion, WAsP, RETScreen, TCHAD

1. Introduction

The negative effects of fossil fuels on the environment have led scientists to consider the possibility of exploiting renewable energies for electricity generation.

Among these many non-polluting energy resources is wind energy. This energy has grown very rapidly over the past two decades [1], mainly in the northern country because of the favourable wind and the mastery of the technology of exploitation by that country. Aware of this danger, countries embarked towards the end of the last century on the exploitation of renewable energies (Solar, Wind, Geothermal, etc.) because of their own character. As a result, many agreements have been signed at conferences organized by these countries. Agreements to reduce the consumption of these fossil fuels for the preservation of the planet. Thus, on December 12, 2015, COP21 concluded an initial agreement that plans to reduce the increase in the earth's temperature from 2 degrees per century to 1.5 degrees compared to the pre-industrial era. This includes reducing greenhouse gases

(GHGs) by all signatory countries and setting up a green climate fund.

Wind energy is an indirect form of solar energy [2, 3], shows in their work on wind turbines the influence of temperature, speed and wind direction on wind power production. The same conclusions were drawn by Lima [4], in their studies on offshore wind turbines. This should lead to consider these parameters for a wind study. It is also important to know the variation of these parameters over a given period of the year, to better quantify the energy potential, because wind speed being one of the most important parameters of wind potential, its annual and seasonal variation in the short and long term greatly influences the return of an investment [5].

According to the bibliography, no serious mapping studies are being done in this area in Chad. Therefore, it is necessary, after mapping the wind in the study area, to show that it is possible operate a wind turbine in the two sites in Chad (N'Djamena and Faya) and which is profitable in relation to with fossil fuels. To carry out this study, two geographic areas of Chad were chosen taking into.

2. Material and Methods

2.1. Anemometer and Weather Vane

The main hardware that has been used for data collection is a Vantage data acquisition station. The definition of this station is to consolidate the bulk of the measurement possibilities in a compact acquisition plant. It includes a weather vane anemometer, a rain gauge with self-bouncer tilting, a passive weather shelter with its accurate thermo-hygrometer. The console, provided with the station allows the visualization of data in real time on its large screen. It is also equipped with the pressure sensor barometric and indoor humidity and temperature sensors. When it is connected to a computer, its possibilities are further expanded. The radio range is about 300 m outside in open fields. The power of the acquisition plant is provided by a solar panel and, is rescued by a lithium battery.

Figure 1. *Vantage Weather Data Acquisition Centre.*

2.2. Terminal

Measurement results are read on a terminal. In this dial, can read: time, wind speed, direction, humidity…

Figure 2. *Terminal.*

3. Introducing Digital Tools

3.1. Golden Software

Golden software is a specialized tool for the development of the topographic map. The latter has a grid-based mapping program that interpolates data irregularly spaced XYZ in a regularly spaced grid. The grid is used to produce different types of maps including cutting, vector, image, shady relief, 3D surface, and 3D wireframe maps. Generally, gridding and mapping options are available to produce the map that better represents data.

3.2. Wind Atlas Analysis and Application Program (WAsP)

WAsP (Wind Atlas Analysis and Application Program) is a computer-based program developed by the Department of Wind Energy at the Technical University of Denmark for vertical and horizontal extrapolation of wind climate statistics.

It is a commercial software for wind data analysis, wind atlas generation, wind climate estimation, wind power production calculations and location wind turbines. Predictions are based on wind data measured at stations in the same region. The program includes a complex terrain flow model, a roughness change model and an obstacle-shelter model. Using a wind atlas dataset, the program can estimate the wind climate at any time at any point and at any height by performing the reverse calculation as it is used to generate a wind atlas. By introducing land descriptions around the predicted site, models can predict the expected actual wind at this site, the average annual energy production of a wind turbine by providing its power curve, estimating wake losses for each turbine in one farm, the net annual energy production of each wind turbine and the entire farm.

3.3. RETScreen

RETScreen is a Clean Energy Management Software system for the feasibility analysis of energy efficiency, renewable energy and generation projects as well as for energy performance analysis. It enables professionals and decision-makers to quickly identify, evaluate and optimize the technical and financial viability of potential clean energy projects. This decision-making intelligence software platform also allows managers to easily measure and verify the actual performance of their facilities, as well as to find additional opportunities for savings and energy production.

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4. Mathematical Modelling

4.1. Probability Density Function

The Weibull distribution is a special case of the Pearson distribution [2]. 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.

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

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 [6].

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

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 [7, 8].

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 $n = 1/k + 1$

4.2. 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 [2, 8]. Since wind data are available in the format of frequency distribution, the recommended method is the modified maximum likelihood method [9]. Weibull parameters are determined using equations (5) and (6):

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

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

Where Vi is the midpoint of the interval of speeds in 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.

4.3. 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 [10]. A length scale called roughness length very often parameterizes the roughness of a territory. Lettau formulated a simple empirical relationship between the roughness elements and the roughness length [11].

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

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

4.4. Obstacle Modeling

Near an obstacle, such as a building, the wind is strongly influenced. Buildings and trees, which influences the data gathering. The exploitation of those requires taking into account the various obstacles of the site, surround the mast of the anemometer to the airport. Model the obstacle as follows:

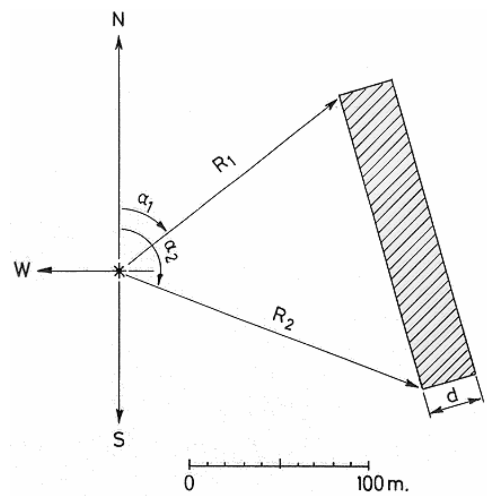

Figure 3. *The model of the obstacle.*

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

1. α1, angle en (°) between the geographical north and the first corner;
2. R_1, radial distance (m) to the first corner;
3. α_2, angle en (°) between the geographical north and the second corner;
4. R_2: radiale distance (m) to the second corner;
5. h, height of the obstacle in (m);
6. d, depth of the obstacle in (m);
7. P, estimates of the porosity of the obstacle...

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

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 [12].

4.5. Pedoclimatic Requirements

The wind turbine can pump groundwater, which could be an initial solution for people living in remote areas. The main ecological and cultural requirement of the date palm for normal production are show in table 1.

Table 1. *The main ecological requirement.*

Climate adaptation	hot, dry and sunny climate
duration of drought tolered	5 - 7 months
Annual water requirement	15 000 - 20 000 m^3/ha
Pedological adaptation	any type of soil, but better in fairly light, deep soil with neutral Ph

4.6. Estimated Pumped Flow

The weibull parameters are essential given that one does not have, at these heights, measurements on site making it possible to describe the mode of the wind. The weibull probability density function, being dependent on the heigh wich was used for the evaluation study, us 40 m. observation shows that under the same operating conditions. In case of study, chose the rotary dynamic pump. This observation is in perfect agreement with that made by Sathyajith S. and Mathew SATHYAJITH ET K. P. PANDEY [2, 13]. The discharge of an ideal roto-dynamic pump [14] at any speed V can be estimated by using the equation (8) and (9) below:

$$Q_R = T\int_{Vi}^{Vo} Q(V)f(V)dV \tag{8}$$

$$Q_R = \frac{1}{8}kC_{pd}\eta_{pd}D_T\frac{\rho_a}{\rho_w}\frac{V_d^3}{gH}\frac{G\lambda_d}{N_{pd}}T\int_{Vi}^{Vo}\left(\frac{V}{C}\right)^k \exp\left[-\left(\frac{V}{C}\right)^k\right]dV \tag{9}$$

4.7. Economic Analysis

Planning for a wind farm over a predefined lifespan can be argued by an analysis of the cost of the kWh produced. The cost of conversion systems depends on:

The cost of investment Operating costs;

Maintenance costs; the state of operation;

The location of wind turbines the cost of this wind energy can be used to calculate the value PVC costs (for estimating the cost of producing wind power).

Thus, the estimate of the cost of the kWh of the energy produced by different wind turbines is given the next Relationship [14, 15].

$$CPU = \frac{PVC}{E_{totale}} \tag{10}$$

Where Ee represents energy production over the life of an Ee wind turbine [16]. While the cost of the present PVC value is given by equation (11) under the following assumptions:

$$PVC = I + C_{OMR}\left(\frac{1+i}{r-i}\right)\left(1-\left(\frac{1+i}{1+r}\right)^n\right) - S\left(\frac{1+i}{1+r}\right)^n \tag{11}$$

This equation had been taken in account when calculating the cost per kWh of energy by the turbine of N'Djamena and Faya.

The cost calculation was made under the following assumptions:

The PVC method is used to determine costs:

1. The life span of the machine (n) as designed by the manufacturer is 20 years [Wind turbines- part 12-1];
2. The interest rate (r) and the inflation rate (i) are 8 and 9 per cent respectively [17];
3. The Cost Comr is a significant part of the total annual wind farm cost, but its value is not fixed. The operating cost varies each year with the variation in the rate of inflation and interest. However, it is admitted that (Comr) varies from 15 to 30% of the total investment cost (wind turbine cost+ other cost) since the technology of wind turbine is not yet well developed in Republic of Chad. In this study, it is admitted that the annual cost C_{omr} is 25% of the investment cost of the wind turbine system studies (price of the system/ life span) [18];
4. The factor (S) is a supplementary cost for most wind turbine farms, located at the proximity of sahelien zone of the country. The cost of installation (notably the cost of civil engineers, the transportation of turbines and the construction of roads) are always high, compared to the cost that could have been incurred if the wind farm was located at urban areas. It is noted here that (S) is equal to 10% of the wind turbine cost:

$$E_e = P_e \, . \, T \tag{12}$$

5. Results and Discussion

5.1. Wind Potential of the Airport Site at the Height of the Collection

Wind speed measurements were grouped in intervals and associated with their frequencies at the site. This mode of representation gives information on the number of hours for which the speed is within a specific interval. Those at the N'Djamena and Faya airport site are presented at table 2 and table 3.

***Table 2.** Wind speed under frequency distribution format for the city of N'Djamena in (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					

***Table 3.** Wind speed under frequency distribution format for the city of Faya in (m/s).*

Speeds	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
Frequencies	6.4	2.2	9.7	15.6	13.1	14.6	13	10.8	8.2	5.4
Speeds	10-11	11-12	12-13	13 14	14-15	15-16	16-17	17-18	18-19	-
Frequencies	3.1	1.4	1.5	1.3	1.1	1				

Weibull's parameters for both sites are given respectively: C-4.2 m/s; 1.44 and C 1.69 m/s;k 6.2. The rose of the winds shows the distribution of wind traffic according to the direction on the site. It allows to know the direction of the prevailing wind. Atmospheric circulation at ground level is mainly driven by the north-easterly wind for the city of N'Djamena and north-northeast for the city of Faya. Frequent analysis of wind speed highlights the predominant speed classes. Therefore, depending on the characteristics of the wind turbines available on the market, one can choose the ones that provide the best performance. The distribution of wind speed by classes is studied, with the frequency expressed directly (as a percentage), which allows to know the probability that a speed value will not be exceeded.

As these parameters are known, it is possible to represent on the same graph the probability density function and the speed frequency histogram.

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As these parameters are known, it is possible to represent on the same graph the probability density function and the speed frequency histogram.

5.2. Annual Wind Map in the City of N'Djamena and Faya

The value of mapping the resource lies in being able to determine how the speed on the site is based on its topography. This representation of the distribution of speed allows to select the most suitable sites that can accommodate a wind project. The speed extrapolation was done at 100 m. In this topographical map, notice three dominant colors:

1. The blue zone, which represents the area with the lowest potential wind turbine with an average speed of 6.95 m/s for the city of N'Djamena and 15 m/s for the city of Faya.
2. The green zone represents the average speed zone;
3. The red zone, represents the area with the highest potential wind turbine following the northeast direction according to the wind rose with a speed of 7.12 m/s depending on the direction North-East for the city of N'Djamena and 16.4m/s following the north-east direction for the city of Faya.

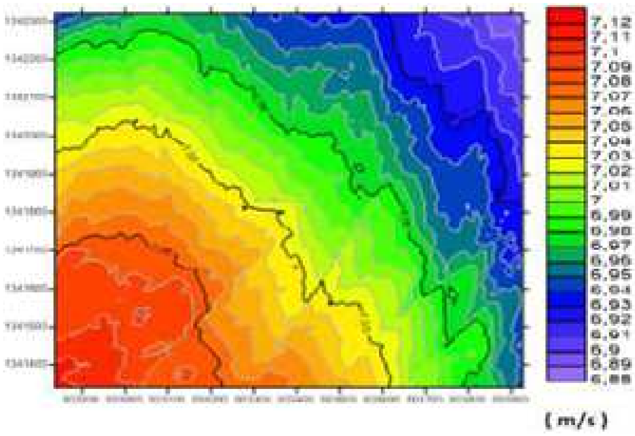

***Figure 4.** Annual Wind Speed Map of the City of N'Djamena (m/s).*

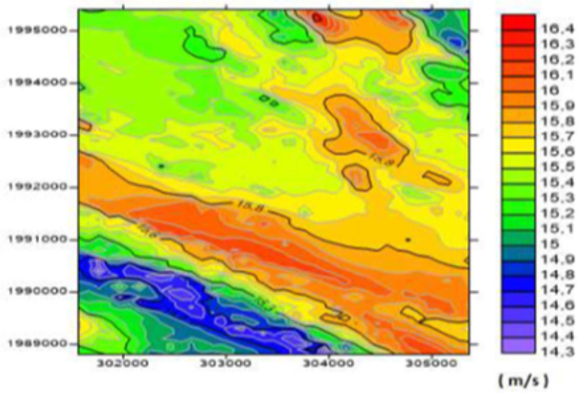

***Figure 5.** Annual Wind Speed Map of the City of Faya.*

5.3. Mapping Annual Energy Production

1. The blue zone, which represents a power of 5.24 GWh in N'Djamena;

2. While in Faya is 9.43 GWh;
3. The green zone represents the average area of power;
4. The red zone, which represents a power of 544 GWh in N'Djamena and Faya in 9.62 GWh respectively.

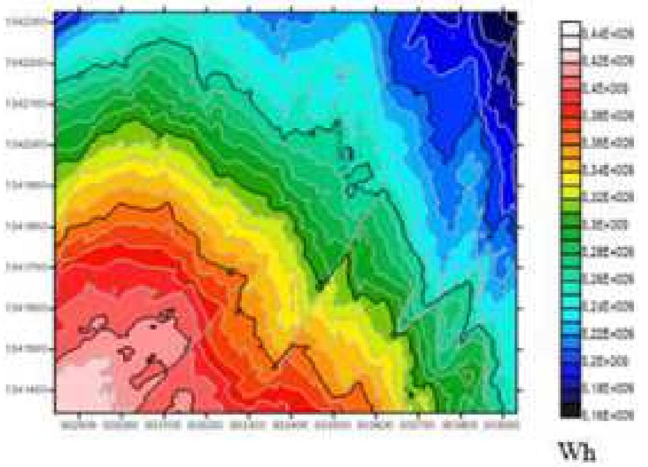

Figure 6. *Map of the distribution of electricity in the city of N'Djamena (GWh).*

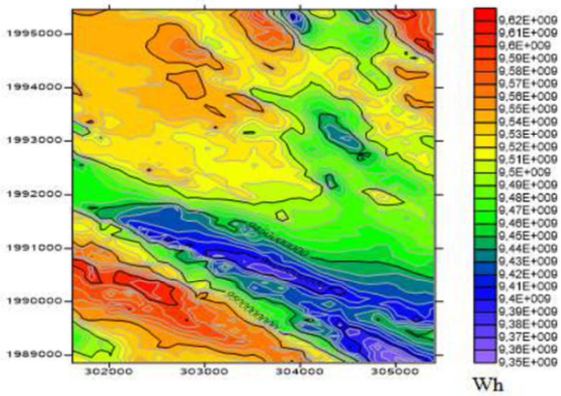

Figure 7. *Map of the distribution of 2D electricity in the city of N'Djamena (GWh).*

5.4. Choice of Wind Generator

The power output of a wind turbine varies with the action of the wind on the rotor. Indeed the developed power curve grows with speed. Choosing a wind turbine criteria such as: start-up speed, mast height, mast height,

developed maximum power and air density. The wind turbine, which chose for site, is the V82 model of the manufacturer Vestas.

Table 4. *Features of the Vestas V82 wind turbine.*

Charateristics	Specifications
Boot speed*	3,5 m/S
Mast height	100 m
Diameter of roto	30 m
Maximum power	1,8 M
Density	1,225 kg/m^3
Manufacturer	Vestas.Wind.system

Table 5. *Total energy production, the Present Value Cost (PVC) and the cost of a kWh (CPU) for 20 years.*

Variables	N'Djamena	Faya
PVC ($;)	490. 03661.85	501. 10513.21
TEP (KWh)/20 ans	1. 1 38. 652. 52	168.1267.97
CPU ($/KWh)	0,097	0.067

5.5. Cumulative Cash Flows

The model calculates the simple return, that is, the time, in years; it takes to recover the initial cost of the investment project from the revenues it generates. The basic assumption of the period method is as follows: for example, in the case of setting up an energy project, a negative repayment period would indicate that the annual costs incurred are higher than the saving annuals carried out. The estimate each year of the sums of money that are disbursed or collected for the project. The cumulative cash flow year after year, wich represents all the expenses and realized gains. When analysing the curve, realize that the project becomes financially profitable from the year when the flow becomes positive.

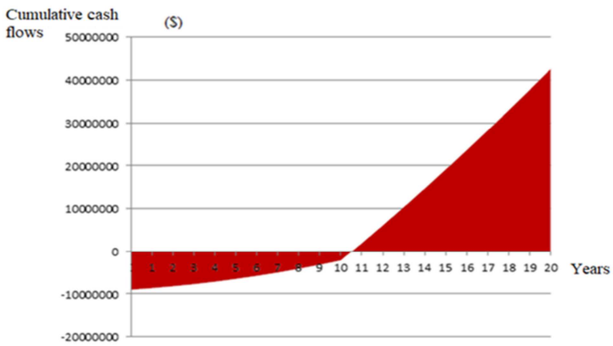

Figure 8. *Graphic of cumulative N'DJAMENA cash flows.*

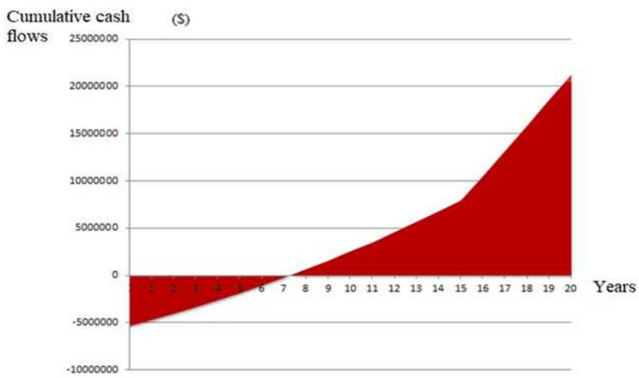

Figure 9. *Graphic of cumulative Faya cash flows.*

5.6. Gross Annual Production of Greenhouse Gas Emissions

According to the literature, Chad emits approximately 5546, 9t CO_2 each year with a GHG emission factor of 0,204t CO_2 /MWh. The project will reduce GHG emissions by 93%.

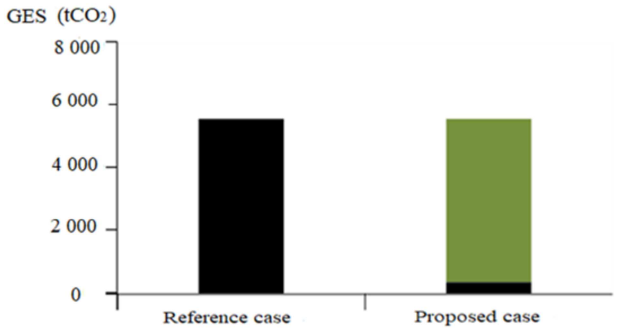

Figure 10. *Graph of annual cash flows.*

5.7. Extrapolated Weibull Settings

Weibull parameters are essential, as do not have, at these heights, on-site measurements to describe the wind regime. The Weibull probability density function, being dependent on the height that was selected for the evaluation study is 40 m. The observation shows that under the same operating conditions. In case study, chose the dynamic roto pump. This observation is in perfect agreement with that made by Sathyajith and Pandev [13]. The dynamic roto pump at an annual rate of 4,577 m^3/h.

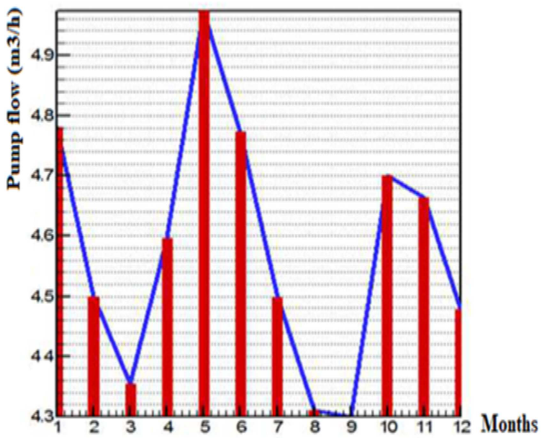

Figure 11. *Monthly volume flows.*

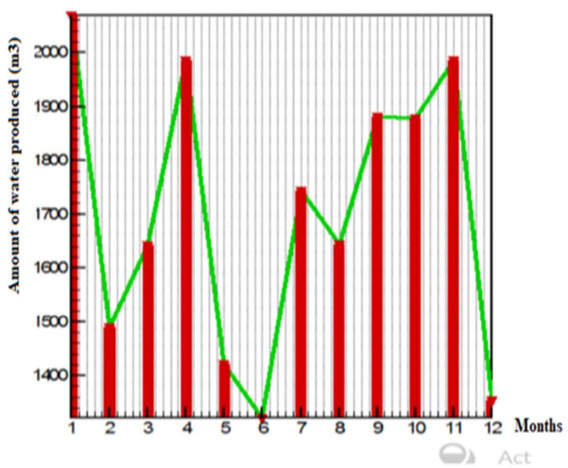

Figure 12. *Pump water flow.*

The expected volume of water is 20,417 m^3. Assuming that the average water consumption is 148 litres per capita per day (www.futurasciences.com), the expected water volumes would serve approximately 1,655 people per year. For a date palm culture, suitable for cultivation in the locality. The annual water need is in the range of 15,000 to 20,000l/ha [19].

The potential for wind pumping could be a solution to the problems of access to water for the benefit of populations in rural areas.

6. Conclusion

This work consisted of the techno-economic and comparative evaluation of the wind potential and application to the date palm of the Republic of Chad. With this in mind, undertook to estimate the wind resource at N'Djamena and Faya, two sites in the Chad area. The estimate of wind potential is delimited respectively by latitude 12°07’36.24’’N and longitude 15°01’48.49’’E in N'Djamena while in Faya, they are respectively longitude 17°55’05.01’’E and latitude 19°06’23.75’’ N using the WAsP software.

Statistical processing of raw wind speed data allowed an analysis giving monthly variations in the distribution of wind speeds, average power density and Weibull parameters K and C. The carefully collected topography and roughness data, structured in vector format, were the basis of the processing carried out by WAsP.

The Weibull parameters characterizing the site are respectively 4.2 m/s and 1.44 at N'Djamena while at Faya of 6.2 m/s and 1.69, which means that the wind speed is variable at both sites: N'Djamena and Faya.

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Roughness, wind profile and topography determine the location of wind turbines. Electricity is produced once the wind turbine is installed. It appears that at 100 m in height, the average wind speed and wind energy density are respectively 7.40 m/s and 746 W/m^2 in N'Djamena while in Faya, they are respectively 14.22 m/s and 4414 W/m^2 for the privileged.

The electrical energy that can be generated based on the previously evaluated wind potential and the power curve of the Vestas V80 and Vestas V82 wind generator. approach was motivated by the need to develop the wind potential of the selected sites, with a view to proposing solutions that could contribute to the realization of the energy crisis experienced by the country's populations and in particular those living in remote areas. Net annual energy production is given respectively of 5.068 GWh in N'Djamena while in Faya is 9.316 GWh.

With regard to pumping, the wind resource at the Faya site is sufficient to consider an application for water pumping purposes. The expected annual water volumes for the dynamic rotor pump is 20,417 m^3. With such volumes of water, up to 1655 people/year could be served. The application that has been made of the use of wind resources in the Saharan region should guarantee the supply of groundwater for the benefit of the population in order to ensure the security of agricultural production and food security and, finally, to solve the problem of water supply to livestock in areas where livestock are reared. Finally, a techno-economic financial analysis of wind potential was made in the N'Djamena and Faya sites. It shows that the KWh costs for the wind power plant in the city of N'Djamena and Faya are 0.097$ /KWh and 0.067 $ /KWh respectively. As a perspective, will take into account, in numerical simulations; interactions between wind turbines still called wake effect this in order to provide a correct estimate of the energy production of a wind farm.

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