Wind energy resource assessment of desert sites in Algeria: energy and reduction of CO₂ emissions

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ABSTRACT
This paper presents a statistical analysis of wind potential of four locations in southern Algeria, namely Adrar, In Salah, Illizi and Tamanrasset, using the Weibull distribution. The evaluation the energy production by the CALORIUS 37 wind turbine taking into account the meteorological (wind and temperature and geographical (latitude, longitude and altitude) datas of these locations. The data were collected every 3 hours over 5 years and used to estimate of the annual energy produced, in order to determine the amount of three types of fossil energy (natural gas, gasoil and gasoline) preserved and the quantities of CO₂ that can be avoided. The shape parameter k, varies from 2.0 (Illizi and Tamanrasset) to 2.48 (In Salah), this means that all the distributions are stable, while the scale parameters C varies from 4.6 m/s (Illizi) to 6.3 m/s (In Salah) and mean velocity v varies from 4.1 m/s (Illizi) to 5.5 m/s (Adrar), while the annual energy produced by CALORIUS 37 range from 4467.6 kWh (Illizi) to 8409.6 kWh (Adrar), the equivalent of energies range from 0.38 TEP (Illizi) to 0.72 TEP (Adrar) and the amount of carbon dioxide (CO₂ ) that we can provide varies from 0.90 TE-CO₂ (natural gas power plant in Illizi ) to 2.24 TE-CO₂ (gasoil power plant in Adrar).

Keywords: Algeria, Carbon, Energy, Weibull, Wind

1. INTRODUCTION
The high consumption of fossil fuels has released into the atmosphere for two centuries, very large quantities of carbon dioxide from the carbon accumulated in the subsoil since the Paleozoic [1]. The resulting increase in atmospheric CO₂ concentration is the main factor of global warming [2]. In 2007, the Intergovernmental Panel on Climate Change (IPCC) states that human activities are responsible for climate change with a very high degree of confidence (= about 90% probability) [3]; In 2014, the IPCC also published a report classifying sources of electricity production based on their greenhouse gas emissions [4].

Greenhouse gases (GHGs) are a problem. They are gaseous components that absorb infrared radiation from the Earth's surface and contribute to the greenhouse effect. Increasing its concentration in the Earth's atmosphere is one of the greenhouse agents [5-8]. For the whole period 1960-2014, Algeria records an annual average of 65903.46 tons of CO₂ [9]. The change between the first and last year is 2260%. The highest value was recorded in 2014 (145400.22 tons) [10] and the lowest value was recorded in 1963 (5427.16 tons), the value estimate that 2020 is about 171022 tones [11].

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This forecast has a very high level of reliability since the variations of the last five available values have a very linear structure (correlation coefficient equal to 0.97) [12]. In the short term, we have inexhaustible renewable energy resources, which we can exploit more and more easily and cleanly. Nevertheless, neglected for a long time, the techniques of extracting the power of these resources call for more in-depth research and development aimed at making them more reliable, lowering costs (for manufacturing, use and recycling) and increasing energy efficiency [13, 14].

Renewable energies are energy sources that use natural resources considered inexhaustible (wind, sun, tides, waterfalls, earth, plants....) it is the only solution; these energies do not produce greenhouse gases, and the discharge of pollutants, and do not generate or waste little waste. They do not use the planet's fossil resources, such as natural gas or oil, whose reserves are declining [15, 16]. Algeria is committed to renewable energies to protect the environment while reducing reliance on fossil fuels, this strategic choice is motivated by the huge potential in solar energy. This energy constitutes the major axis of the program which devotes to thermal solar and solar photovoltaic an essential part [17-19].

Solar energy is expected to reach more than 37% of national electricity generation by 2030; this program does not exclude wind power which is the second axis of development and whose share should be around 3% of electricity production in 2030 [20]. The study of the wind potential is important in order to locate the site of settlements for the future wind development zone, the estimate of the wind potential in Algeria has shown that, the Mediterranean region characterized by a low wind speed, but the Sahara region is windy [21-30].

The present study attempts to evaluate wind potential of four locations in southern Algeria. The evaluation the energy production by the CALORIUS 37 wind turbine taking into account the meteorological (wind and temperature and geographical (latitude, longitude and altitude) datas of these locations. The data were collected every 3 hours over 5 years and used to estimate of the annual energy produced, in order to determine the amount of three types of fossil energy (natural gas, gasoil and gasoline) preserved and the quantities of CO₂ that can be avoided.

2. WIND DATA

Explaining research chronological, including research design, research procedure (in the form of algorithms, pseudocode or other), how to test and data acquisition [1-3]. The description of the course of research should be supported references, so the explanation can be accepted scientifically [2, 4]. From the wind data collected in the meteorological stations of the sites studied, we mainly focused on annual average wind speeds at 10 m from the ground. The statistical study is based on the processing of collected data every 3 hours, during the last 5 years for the selected sites. The statistical distribution of Weibull is appropriate for the study of the wind speeds distribution, this distribution function can be written as follows [31-44]:

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

(1)

The shape parameter k characterizes the distribution symmetry and the scale parameter C is very close to the mean wind speed, in order to determine the two parameters k and C, the standard deviation method has been used to determine theses parameters as shown in (2) and (3) [37].

\[
k = \left( \frac{\sigma_v}{v} \right)^{1.09}
\]  

(2)

\[
C = \frac{v}{\Gamma\left(1+\frac{1}{k}\right)}
\]  

(3)

Weibull parameters and mean velocity were calculated for the four sites studied at 10 m from the ground as shown in Table 1. From table, It can be observed that the values of the shape parameter k, varies from 2.0 (Illizi and Tamanrasset) to 2.48 (In Salah), this means that all the distributions are stable, while the scale parameters C varies by 4.6 m/s (Illizi) at 6.3 m/s (Adrar) and mean velocity v varies from 4.1 m/s (Illizi) to 5.5 m/s (Adrar). If we refer to the classification of the national physical laboratory NLP, the data are classified as class 3.
we note that In Salah is considered a favorable area for the development of wind energy, it is in class (03), so the region of Adar is in the class (04), he also found appropriate wind turbine explosion, for the other two sites the wind speed is weak to install a wind farm.

Table 1. Weibull parameters and mean velocity at 10 m from the ground
(collected data every 3 hours over 5 years)

| Site    | C (m/s) | k   | $\bar{v}$ (m/s) |
|---------|---------|-----|-----------------|
| Adrar   | 6.3     | 2.12| 5.5             |
| In Salah| 6       | 2.48| 5.3             |
| Illizi  | 4.6     | 2.00| 4.1             |
| Tamanrasset | 5.1 | 2.00| 4.5             |

3. WIND ENERGY
3.1. Power
The wind power relation for wind speeds $v$, section $S$ and air density $\rho$ is expressed by (4) [45-50]:

$$P(v) = \frac{1}{2} \rho S v^3$$

(4)

The reference air density (1.225 kg/m$^3$) corresponds to the density of air at sea level (for the temperature of 15 °C and the pressure $P = 1013.3$ mbar), is used in the power curves for the manufacturers of the wind turbines, but the air density is a local parameter, where it depends on atmospheric pressure and temperature at each location. Assuming that air is a perfect gas we can conclude the following report [37]:

$$\rho = \frac{335.49}{T} \exp\left(-\frac{0.034 Z}{T}\right)$$

(5)

where $Z$ is the altitude (m) and $T$ is the temperature (°k).

The wind speed data are measured at a height of 10 m, while the wind speed changes with the heights. The extrapolation expression of the Weibull parameters is used to extrapolate the parameters $k_1,C_1$ from reference height $Z_1$ to the parameters $k_2,C_2$ at the hub height $Z_2$, which can be expressed by (6-8) [51].

$$\frac{k_2}{k_1} = \frac{1-0.08881 \ln \left(\frac{Z_2}{10}\right)}{1-0.08881 \ln \left(\frac{Z_1}{10}\right)}$$

(6)

$$\frac{C_2}{C_1} = \left(\frac{Z_2}{Z_1}\right)^{\alpha}$$

(7)

with

$$\alpha = \frac{0.37 - 0.08881 \ln\left(C_1\right)}{1-0.08881 \ln\left(\frac{Z_1}{10}\right)}$$

(8)

The wind turbine can convert wind aerodynamic energy into electrical energy, where the wind electric power can be written in (9) [38].

$$P_e(v) = C_e(v)\rho(v)$$

(9)
The coefficient of efficiency of the wind turbine $C_e$ can be written in the form of a polynomial [23, 24, 38]:

$$C_e(v) = \sum_{i=0}^{6} \alpha_i v^i \quad \text{if} \quad v_d \leq v \leq v_a$$

$$C_e(v) = 0 \quad \text{if} \quad v_d > v \quad \text{or} \quad v > v_a \quad (10)$$

where $v_d$ is cut-in wind speed (m/s) and $v_a$ is cut-out wind speed (m/s).

The wind turbine parameters of stander model are listed in the Table 2 and the power output curves for the reference air density presented in Figure 1. From Figure 2, it can be observed that the annual average power range from 0.51kW (Illizi) to 0.96kW (Adrar), we noticed that the average power depended to the wind turbine diameter and climatic conditions (wind speed and temperature) as well as the efficiency of this the wind turbine. The power curve (kW) was superimposed on the frequency Weibull curve $H(v)$ (%) to evaluate the average power produced by a wind turbine, show in (11) [38, 52]:

$$\bar{P} = \sum_{v_i=v_d}^{v_a} P_i(v_i) H_i(v_i) \quad (11)$$

![Figure 1. CALORIUS 37 powers curves [53]](image)

![Figure 2. Average of power produced by CALORIUS 37](image)

**Table 2. Wind turbine parameters [53]**

| Name          | $P_i$ (kW) | $D$ (m) | $Z_2$ (m) | $v_d$ (m/s) | $v_a$ (m/s) |
|---------------|------------|---------|-----------|-------------|-------------|
| CALORIUS 37   | 5          | 5       | 15        | 3.5         | 20          |

3.2. Energy

The energy produced by a wind turbine for $N$ hour in one years is calculated by (12) [38]:

$$E_w = N \times \bar{P} \quad (12)$$

From Table 3, it can be said that the annual energy produced by CALORIUS 37 range from 4467.6 kWh (Illizi) to 8409.6kWh (Adrar), the equivalent of energies which vary from 0.38 TEP (Illizi) to 0.72 TEP (Adrar). This means that using a one turbine for one year will save about 803369.09 m³ of natural gas or 0.71 ton of gasoil or 0.69 tones of gasoline at Adrar; for In Salah, we can do without 744790.09 m³ of natural gas 0.66 tons of gasoil or 0.64 tons of gasoline, in Tamanrasset can save 468631.97 m³ of natural gas or 0.42 tons of gasoil or 0.40 tons of gasoline; finally, we can win 426789.83 m³ of natural gas or 0.38tons of the gasoil or 0.36 tons of the gasoline in Illizi. From Figure 3, it can be said that the amount of carbon dioxide (CO₂ ) that we can provide varies from 0.90 TE-CO₂ (Natural gas power plant in Illizi ) to 2.24 TE-CO₂ (gasoil power plant in Adrar).

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Table 3. The annual energy produced by CALORIUS 37 and its fossil fuel equivalence

|           | Adrar   | Salah  | Illizi  | Tamanrasset |
|-----------|---------|--------|---------|-------------|
| Energy (kwh) | 8409.6  | 7796.4 | 4467.6  | 4905.6      |
| Energy (TEP) | 0.72    | 0.67   | 0.38    | 0.42        |
| Natural Gaz (m³) | 8.03 E05 | 7.48E05 | 4.27E05 | 4.69 E05    |
| Gasoil (ton)  | 0.71    | 0.66   | 0.38    | 0.42        |
| Gasoline (ton) | 0.69   | 0.64   | 0.36    | 0.40        |

Figure 3. The amount of carbon dioxide (CO₂)

4. CONCLUSION

This study focused on the evaluation of the wind potential and energy produced by small wind turbine in Algerian Sahara. The results obtained are: (a) The shape parameter k, varies from 2.0 (Illizi and Tamanrasset) to 2.48 (In Salah), this means that all the distributions are stable, while the scale parameters C varies by 4.6 m/s (Illizi) at 6.3 m/s (Adrar) and mean velocity v varies from 4.1m/s (Illizi) to 5.5 m/s (Adrar); (b) The annual average power range from 0.51kW (Illizi) to 0.96kW (Adrar), we noticed that the average power depended to the wind turbine diameter and climatic conditions (wind speed and temperature) as well as the efficiency of this the wind turbine; (c) The annual energy produced by CALORIUS 37 range from 4467.6 kWh (Illizi) to 8409.6kWh (Adrar), the equivalent of energies which vary from 0.38 TEP (Illizi) to 0.72 TEP (Adrar); (d) The amount of carbon dioxide (CO₂) that we can provide varies from 0.90 TE-CO₂ (Natural gas power plant in Illizi ) to 2.24 TE-CO₂ (gasoil power plant in Adrar).

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