Assessment of wind and solar energy resources in Batna, Algeria.

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Abstract
Due to several climate changes caused by greenhouse gas and to the increasing need for clean energies, scientists drew attention to renewable energy sources, which are the most suitable solution in the future. Sparsely populated and flat open terrains observed in Batna region (North East of Algeria) and its semi-arid climate, make it a promising region for the development of solar and wind energies.

In this article, we analyzed ten years of daily wind speed data in a remote area of Batna: Mustafa Ben Boulaïd Airport. Wind power availability, as well as annual mean values of wind speed and power, were estimated. Frequency distribution of daily totals of wind speed data were counted and illustrated too.

The results have been used to estimate net energy output of different wind turbines. This simulation shows a difference in wind generators production and allows us to choose the best wind turbine adapted to site conditions.

Since solar and wind energy resources may be used to compensate each other, we evaluated also the solar potential of the same area.

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Key words: Wind energy, Weibull, solar irradiation, Linke factor.

1. Introduction

Algeria has set up a national program for the promotion of renewable energy sources in the frame of its sustainable energy development plan for 2020. This program has been concretized by the creation of the NEAL (New Energy Algeria) which is Algeria renewable energy agency [1].

Actually, wind and solar energy are considered us the most important renewable energy resources and both of them can be combined to compensate each other, the so-called hybrid system. We can optimize

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energy output of such system by adding another "spare wheel" which is diesel energy in case of insufficient of the two other resources, creating a tri-hybrid system. Hybrid systems are now a possible economical alternative for running the classical electric grid all the way to the isolated and remote areas. At the other hand, these areas need energy for especially domestic and agricultural applications that are largely covered by small or intermediate-scale wind generators available in the commercial wind turbine market.

This concept of hybrid system in remote areas has been already exploited in many countries: Danmark, Egypt, India, Libya...etc [2, 3]. Remote areas may include, not only villages and rural zones, but also military installations, desalinations plants, telecommunication stations, and remote stations for data logging of environmental parameters [4]. There are some authors who tried to create logistical models to evaluate the prediction of energetic performance of hybrid systems in remote areas, and also to optimize sizing of the generating groups and energy storage [5].

Our study aims to establish an accurate assessment of wind energy resource in the region of Batna located in the North East of Algeria. This region extends form 4° to 7° East longitude and from 35° to 36° North latitude. It has an important and a diversified natural potential (forests and underexploited ground water, fertile grounds and mineral deposits) and its actual principal vocation is the development of the agronomic sector. On the other hand, we can observe the growing number of industrial parks and varying utilities like Batna airport and new agglomerations at its periphery.

2. Material and methods

The meteorological station of Batna located near Batna International Airport, where wind and solar data were collected, is situated exactly at 35.76° of latitude, 6.3225° of longitude, and it is elevated 821m above sea level.

2.1. Wind data collection

Wind data was collected every 3 h at 10m above ground level (AGL) during 10 years (from 1999 to 2008). Wind speed and direction were measured, respectively, using a cup-type anemometer and a weathercock. Windographier software was used to analyze raw wind data.

2.2. Calculation

2.2.1. Wind speed extrapolation

There are models reported in the literature which can be employed to extrapolate upwards from the height at which wind speed data was collected to estimate the wind speeds at higher heights [6, 7, 8]. According to the studies dealing with the surface boundary layer, the variations of wind speed with altitude can be estimated using the following relationship:

\[ V_2 = V_1 \left( \frac{z_2}{z_1} \right)^\alpha \]  

(1)

where \( V_2 \), in m/s, is the calculated wind speed at height \( z_2 \), \( V_1 \) is the observed wind speed at height \( z_1 \) and \( \alpha \) is the wind speed power law exponent.
The only factor to estimate for this formula is the value of the power law coefficient. It varies following the roughness of the location [9]. The formula that calculates $\alpha$ is:

$$\alpha = \frac{1}{\ln \frac{Z}{Z_0}} \left[ \frac{0.0881}{1 - 0.0081 \ln \frac{Z}{Z_0}} \right] \ln \left( \frac{V_w}{\bar{V}} \right)$$

(2)

With: $\bar{Z} = \exp \left[ \ln Z_1 + \ln Z_2 \right] / 2$

(3)

$z_0$ is the roughness of the location.

After analysis, a value of $\alpha = 0.16$ was found as the power law exponent factor for the station of Batna where $z_0$ value is equal to 0.01 m.

### 2.2.2. Frequency distribution of wind speed

Knowledge of wind speed frequency distribution is a very important factor to evaluate the wind potential in windy areas. The Weibull distribution is the most commonly used model. It is a good match with the experimental data. The idea is that only annual or monthly average wind speeds ($V$) are sufficient to predict the complete frequency distribution of the year or the month [10]. The Weibull probability density function is written as:

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

(4)

$k$ (dimensionless) and $c$ (m/s) are the shape and scale parameters of this distribution deduced from the experimental wind data, respectively.

### 2.2.3. Wind power energy calculation

The electric energy produced by a turbine over the year is given by the following relationship:

$$E = N_h C_p \frac{1}{2} \rho \pi \frac{D^2}{4} \int V^3 f(V) dV$$

(5)

Where:

- $N_h$ is the number of hours over the year (i.e.; 365 x 24 = 8760 h)
- $V$ is wind speed (in m/s), $\rho$ is air density (in kg/m$^3$) it is approximately 1.225 kg/m$^3$ and $D$ is the rotor diameter (in m), $C_p$ is the power coefficient, it characterizes the aptitude of a wind turbine to extract wind energy. It's evaluation is based on Rankine-Froude theory [11,12] and it is given by this formula:

$$C_n = 4\alpha (1 - \alpha)^2$$

(6)

The equation (5) calculates the maximum yearly mean wind energy per unit cross sectional area.
2.2.4. Solar data calculation

Solar data were calculated using Matlab software and free data from website providing information on solar radiation: “http://www.soda-is.com/eng/services/service_invoke/gui_demo.php”.

3. Results and discussion

3.1. Wind speed

Batna annual average of wind speed was found to be 4.36 m/s for the studied period. Long term seasonal wind speeds were found to be relatively higher during the period from March to September (Fig. 1-A). We can say that this period corresponds roughly to a period of maximum demand of electricity because it includes warm season (operating air-conditioners, refrigerators and irrigation pumps). In cold season, the major source of energy used for heating in Algeria is gas energy because it is cheaper than electricity.

We notice that, approximately, higher wind speeds were observed between 09:00 and 18:00. This means that electricity production is the most important during this period of the day, which coincides with higher electricity demand period (Fig. 1-B).

![Figure 1](image)

**Fig. 1.** (A) Seasonal variation of long-term mean wind speed; (B) Mean daily speed.

3.2. Extrapolated wind speed

Considering the fact that rotors of the actual wind turbines are placed at heights varying between 40 and 110m AGL and in order to choose the height of the pylons handling the wind turbines, it is necessary to know the variations of wind speed with altitude.

Thereby, the collected wind speed data was calculated at 40m and 60m hub height using formula (1). At these heights the annual average of wind speed became 5.44 m/s and 5.76 m/s, respectively, while it was only 4.36 m/s at 10m AGL, this corresponds to increases of, respectively, 24.78% and 32.31% from the 10m average annual wind speed (Fig. 2-A).
3.3. Wind speed frequency distribution

Using the Weibull distribution, we found that $k = 1.61$ and $c = 4.91$ m/s. The frequency distribution of wind speed shows in the case of Batna location that wind speed remained at the modal value 3 m/s and below it for about 17% of time during the entire year and above it for the rest of the period (Fig. 2-B).

3.4. Wind energy

Wind energy is the kinetic energy of the moving air mass. Using equation 5, we calculated the maximum yearly mean wind energy per unit cross sectional area of a turbine. Thereby, this entity was estimated for wind energy extracted at different heights: 10m, 40m and 60m (Fig. 3). As expected, mean wind energy is proportional to hub height.

3.5. Comparative simulation of wind turbines

Considering the socio-geographical features and wind potential of the region of Batna, and looking for machines with good performance and reasonable cost, five types of wind turbines from different manufacturers have been chosen (Fig. 4). All these turbines have a "cut-in wind speed" that is inferior to the mean wind speed observed in Batna (i.e.; 4.36 m/s).

As the power output of the studied turbines varies (maximum of 12 kW for Bergey wind turbines and 350 kW for Enercion E33 and Fuhrlander FL 100 turbines), we can divide the selected turbines in tow groups. This is another criterion added to the raison of our choice. Indeed, Bergey wind turbines used in
combination with a back-up diesel generator, and with optional photovoltaics, provide a cost-effective and reliable alternative to conventional methods of electricity supply in remote areas. This fits well with the aim of this study.

At the other hand, the Enercon E33 and Fuhrlander FL 100 turbines chosen here, operate with variable rotor speed and are thus capable of producing electric power efficiently at low wind speeds, and utilizing the energy of gusts without overloading the grid or turbine components. The output energy $E$ of each turbine has been calculated for the region of Batna using Windographer software (Fig. 4).

Four hub heights (10, 20, 40 and 60m) have been considered for this computation concerning the three Bergey turbines (Fig. 4-A). As expected, the energy output increases when hub height augments.

In remote zones, this kind of small wind turbines contributes to supply houses with electricity. As wind is an intermittent phenomenon, other energy resources must be considered in case of strong fluctuations of wind or a total disappearance. This leads to hybrid systems creation. This system of energy conversion has been experimented recently in the houses of Europe and seemed competitive with the classical electric mains. Concerning the two turbines: Enercon E33 and Fuhrlander FL 100, only three hub heights (40, 60 and 80m) have been considered for the computation of the mean energy output (Fig. 4-B).

![Image](image-url)

Fig. 4. (A) Mean energy Output for Bergey turbines and (B) Enercon E33, Fuhrlander FL 100 turbines.

3.6. Solar data

In order to evaluate the solar potential of this site we have used the Capdevou model [13] but with using the new estimation of Linke's turbidity factor. This factor is an important parameter to evaluate the irradiation; it represents the atmospheric turbidity caused by aerosols and water vapor and indicates the number of ideal (clean and dry) atmospheres that produce the same extinction of the extraterrestrial solar beam as the real atmosphere. This parameter was monthly estimated in our site (Fig. 5). We can see that, in summer, the sky is turbid especially in July, but in the worst month (December) the sky is clear.
Simulation of solar irradiance in the site of Batna shows the important solar potential which allows the installation of photovoltaic systems. The worst month (December) is the base of sizing calculation. The month in which we have the best irradiance is May (Fig. 6-A). This site receives almost 1700 kWh/m² of global irradiance and almost 1500 kWh/m² of Beam Irradiance (Fig. 6-B); so we can classify it between the best solar sites in Algeria.

4. Conclusion

The aim of this study was to assess the potential of wind and solar powers in Batna, Algeria. Hourly measured long term wind speed data of Batna during the period of 1999-2008 have been statistically analyzed. The most important outcomes of the wind study can be summarized as follows:

(a) Mean wind speed measured at 10m AGL is determined as 4.36 m/s for the studied period. This speed increases by, respectively, 24.78% and 32.31%, when it is extrapolated to 40 and 60m hub height.

(b) Long term seasonal wind speeds were found to be relatively higher during the period from March to September. and higher wind speeds were observed between the period between 09:00 and 18:00 in the day. These periods feet well with annual and daily periods of maximum demand of electricity, respectively.

(c) The mean annual value of Weibull shape parameter k is 1.61 while the annual value of the scale parameter c is 4.91 m/s.

(d) The frequency distribution of wind speed shows that wind speed remained at the modal value: 3 m/s and below it for about 17% of time during the entire year and above it for the rest of the period, which represents a good advantage for our study.
(e) The maximum yearly mean wind energy per unit cross sectional area of standard wind turbine was estimated at different heights: 10m, 40m and 60m and shows that mean wind energy is proportional to hub height. So we can vary only the rotor diameter D to find the optimal wind turbine(s) for this location.

(f) Five types of wind turbines have been chosen and their power output evaluated at different hub heights. This evaluation confirms that small wind turbines (Bergey Excel-R, Bergey Excel-S and Bergey XL.1) can be used to supply remote regions with small electricity needs (rural zones) while bigger machines (Enrercon E33 and Fujihrlanders FL 100) can be used to supply those with more important electricity demand: airport, new agglomerations, military installations, telecommunication stations…

(g) Small wind turbines (Bergey Excel-R, Bergey Excel-S and Bergey XL.1) can be used in conjunction with other energy resources (solar and/or diesel) in order to compensate wind energy output fluctuations. At the other hand, and in order to provide another source of energy to supply the site, we studied the solar energy potential of the location. The results show that:

(h) The most turbid period is summer (especially in July) contrasting with the less turbid month which is December.

(i) Global and Beam irradiances are almost 1700 kWh/m² and 1500 kWh/m², respectively. This allows us to say that this site is one of the best solar sites in Algeria.

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