Assessment of wind energy and energy cost in Algeria

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Abstract

This paper presents a statistical analysis of wind characteristics and estimating of cost of six locations situated in Algeria, namely Adrar, Annaba, Bejaia, Kacer-Chellala, M'sila and Oran, using Weibull distribution function on wind speed data at 10 m height collected in the last ten years by the Algerian Meteorological Office. The wind energy production using the economic evaluation of various wind generator turbine (WGT) enjoying the 18, 30, 80, 140, 150 and 200 KW rated power size. In Adrar and M'sila , the electricity generation cost per KW from WGT 150 KW does not exceed 0.058 USD /KWh compared to price of electricity in Algeria 0.054 USD /KWh.

Keywords: *Wind, Wind energy, Weibull parameters, Wind rose, Cost estimation, Algeria*

1. Introductions

Renewable energy can be another alternative that allows producing clean and sustainable electricity, with less dependence on conventional resources, provided that natural and random fluctuations are accepted. Today, the low production costs of wind power make it more competitive. It helps reduce greenhouse gas emission in the atmosphere as well. Wind energy by the first decade of the 21st century had a growing importance worldwide, year by year. Indeed, the turbines installed in 2009 accounted [1-3].

Many work indicated that Algeria was characterized by a most important wind potential, in particular, the first approach is the establishment of atlases and maps of wind in Algeria. In this framework, we can cite the work of Wind energy potential in Algeria Kasbadji Merzouk. The second [4] approach is the wind potential assessment and design of systems for converting wind energy. In this regard, one may cite studies of Himri [5] , finally Temporal assessment of wind energy resource at four locations in Algerian Sahara Boudia [6] . The third approach is the evaluation of energy cost. In this context, we can cite the evaluation of electricity generation and energy cost of wind energy conversion systems in southern Algeria Diaf.S [7].

The objectives established by Algerian government, focused on raising renewable energy production to 1400 MW in 2030. Electrical power will be obtained from solar power plants, which are exclusively solar, and wind energy, which also use other forms of renewable or conventional energy, preferably natural gas.

Currently, the total installed wind power in Algeria is insignificant. However, the first wind farm of 10 MW of power will be located in Adrar.

In this study, we propose to carry out a temporal study on wind resource assessment and estimating of cost at six locations using Weibull distribution and the economic evaluation of various wind generator turbine (WGT), taking into account the geographical location of each region, and the variation in air density as a function of temperature.

2. Sites selection and weather data

In this study, the wind speed data were collected over a period of 10 years at site used in this study. The details of the site are summarized in table 1.

Table 1 Geographical coordinates of the data collection stations used in the study

Location	Latitude (°) N	Longitude (°) E	Altitude (m)
Adrar	27.88	-0.28	263
Annaba	36.83	7.81	04
Bejaia	36.71	5.06	02
Kasr-Chellala	35.16	2.31	801
M'sila	35.66	4.50	442
Oran	35.63	-0.60	90

The meteorological measurements were made 10m above ground level and registered every 3hour at station. The geographical locations of this station are shown in Fig1

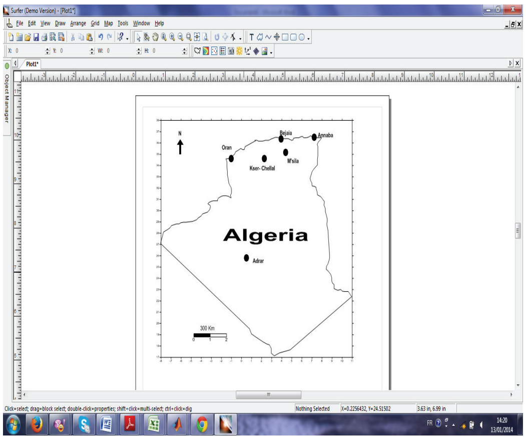

Figure 1. Distribution of meteorological stations over Algeria.

3. Methodology

3.1. Weibull distribution

The wind characteristics will determine the amount of energy that can be effectively extracted from the wind farm. In order to determine the properties of a site, measurements of the speed of wind and its direction are needed. This study was carried out over a period of ten years.

However, previous studies in the field of wind energy showed that the most important and appropriate characteristic to exploit is the Weibull statistical distribution. This is a probability function that can be expressed as[8]:

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

Parameters k and C are the shape parameter (dimensionless) and the scale parameter (m/s), respectively. Usually, the shape parameter characterizes the symmetry of the distribution. The scale parameter is very close to the average speed of wind. The standard deviation method was chosen to determine both factors k and C. This method is based on the calculation of the standard deviation and the average speed [9]

If the wind distribution is desired at some height other than the anemometer level, the advantage of the use of the Weibull distribution is that C and k values can be adjusted to any desired height by the model of Justus [10].

3.2. The capacity factor and wind energy

The power of the wind that flows at a speed v through the blade sweep area S can be expressed by the following equations[9]:

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

Where ρ is density of air (kg/m³)

A wind turbine allows extracting the kinetic energy from the wind and converting it into and electric energy. The power curves of the wind turbines can be expressed by the following equations [11]:

$$P_e(v) = C_e P(v) \tag{3}$$

Where C_e is the wind turbine efficiency, the efficiency the wind turbines taken into consideration in this study are shown in fig2 and. Technical specifications of the selected wind turbines are listed in Table 2.

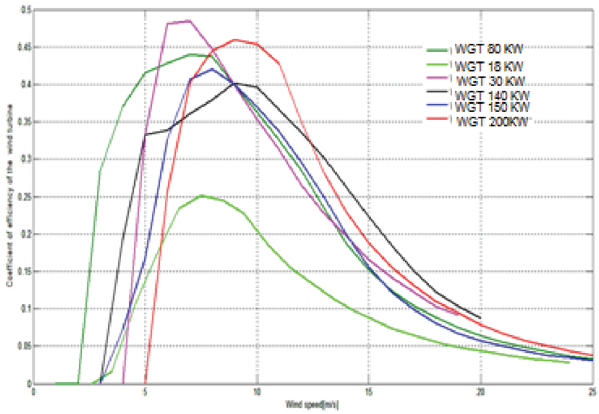

Figure 2. The total efficiency, from wind energy to electric output of the WTG as a function of the wind speed [12].

Table 2 Technical specification of the considered wind turbine[12].

Characteristics	WGT 18KW	WGT 30KW	WGT 80KW	WGT 140KW	WGT 150KW	WGT 200KW
Rated power	18	30	80	140	150	200
Rotor diameter	11	10	18	19.6	25	24
Hub height	18	24	50	26	30	30
Swept area of rotor	95	79	254	302	491	452
Cut-in wind speed	2,6	5	3	4	4	6
Rated wind speed	17.6	30	13	16	13	16
Cut-out wind speed	24	30	25	20	25	25

The capacity factor is defined as the ratio of the average power output to the rated output power of the wind turbine. It can be calculated as follows[9]:

$$Cf = \frac{\int P_e(v) f(v) dv}{P_r} \tag{4}$$

The annual energy generated by a wind turbine can be calculated as follows[9]:

$$E_P = P_r Cf \times 8760 \quad (5)$$

3.3 Energy cost

The initial investment cost is equal to the sum of costs of the units of the components that constitute it. The total investment cost is given as below[11]

$$IC = C_{wt} + C_{bb} + C_{ci} + C_{in} + C_{misc} \quad (6)$$

where C_{wt} is cost of the wind turbine, C_{bb} is cost of battery bank, C_{ci} is civil work and installation cost, C_{in} is cost of the inverter and C_{misc} is miscellaneous cost such as connecting cables, control panel and other components .The cost break-up of a typical WGT project are shown in Fig.3.

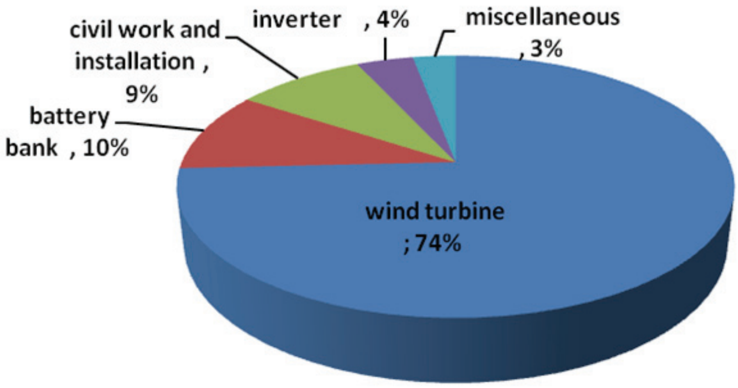

Figure 3. Cost break-up of a typical WGT project.[13].

Cost of wind turbines can vary significantly depending on the type of stock availability and cost of raw materials (steel). The variation can be up to 25-30% of the price. This difference is not negligible because the total cost of purchasing wind is generally 74% of the total project cos. The cost of wind turbine can be determined as follows[11][13]:

$$C_{wt} = C_{spe} P_r \quad (7)$$

Where P_r is the rated power and C_{spe} is the specific cost of turbine systems are summarized in table3;

Table 3 Cost of wind turbines based on the rated power[13].

Wind turbine size (kW)	Specific cost (USD/kW)
10–20	2200–2900
20–200	1500–2300
200>	1000–1600

The present value of costs (*PVC*) can be calculated as follows[11]:

$$PVC = CRF \times IC + C_{om(p)} \quad (8)$$

Where:

$C_{om(p)}$ is the maintenance costs during the system life (*USD*) can be calculated as follows[13][13]:

$$C_{om(p)} = \frac{C_{oma}}{1 - e_{om}} \left[1 - \left(\frac{1 + e_{om}}{1 + r} \right)^n \right] \quad (9)$$

Where C_{om} is the operation a maintenance cost for the first year, e_{oma} is escalation of the operation and maintenance.

CRF is the capital recovery factors for wind turbine can be calculated as follows[13][13]:

$$CRF = \frac{r}{1-(1+r)^{-n}} \qquad (10)$$

The Unite cost energy is the ratio of present value of costs *PVC* of project on electricity produced, can be calculated as follows [13]

$$UCE = \frac{PVC}{E_P} \qquad (11)$$

4. Results and discussion

4.1. Wind data resource

The present study is based on data source measured at a height of 10 m above ground level, for six different locations in Algeria. The wind data were recorded every there hour during a ten-year period, from 2001 to 2010, and were obtained from the Algerian meteorological national office

The form parameter value k for Adrar, Bejaia ,Kaser-Chellala and M'sila account respectively 2.06,2.64,2.34and 2.26, shows that these distributions is stable, whereas the two other sites have a lower value of k, which means that winds are widely dispersed.

Analysis of the scale parameter C shows that Adrar the most windy (7.4 m/s) and the least windy is Annaba (4.3 m/s). The Annual mean wind speed and Weibull parameters at 10m from the ground level of the site are summarized in table5.

Table 4 Annual mean wind speed and Weibull parameters at 10m from the ground level

location	Scale parameter C (m/s)	Shape parameter k	Mean wind speed v (m/s)
Adrar	7.4	2.06	6.5
Annaba	4.3	1.75	3.8
Bejaia	4.8	2.64	4.2
Kasr-Chellala	4.6	2.34	4
M'sila	5.5	2.26	4.8
Oran	4.9	1.84	4.4

Statistical data analysis allowed the determination of the wind rose which is the graphical representation of wind frequency against the direction in a polar reference. It is determined for ten years. The results obtained (see Fig.4) show that:

- In Adrar, the eastern sector represents 15 % of wind frequencies, while the East – North - East (ENE) are predominant sectors with a percentage of around 14 %.
- In Annaba, almost all sectors are equal; however the West direction remains dominant with16 %.
- In Bejaia, the western sector represents 30 % of wind frequencies, while the West-South-West (WSW) and the East directions are two predominant sectors with a percentage of around 20 % each.
- In kasr-Chellala, the prevailing wind direction is West- North –West (WNW) which represents 28 % of episodes and other predominant directions are North-West (NW) and West which have respectively13 % and 11 % of episodes.
- In M'sila, the western sector represents 28 % of wind frequencies, while the East directions are predominant sectors with a percentage of around 25 %.
- In Oran, the prevailing wind direction is the north which represents 21 % of episodes and other predominant directions are west-south-west (SW) and west which have respectively16% and 12% of episodes.

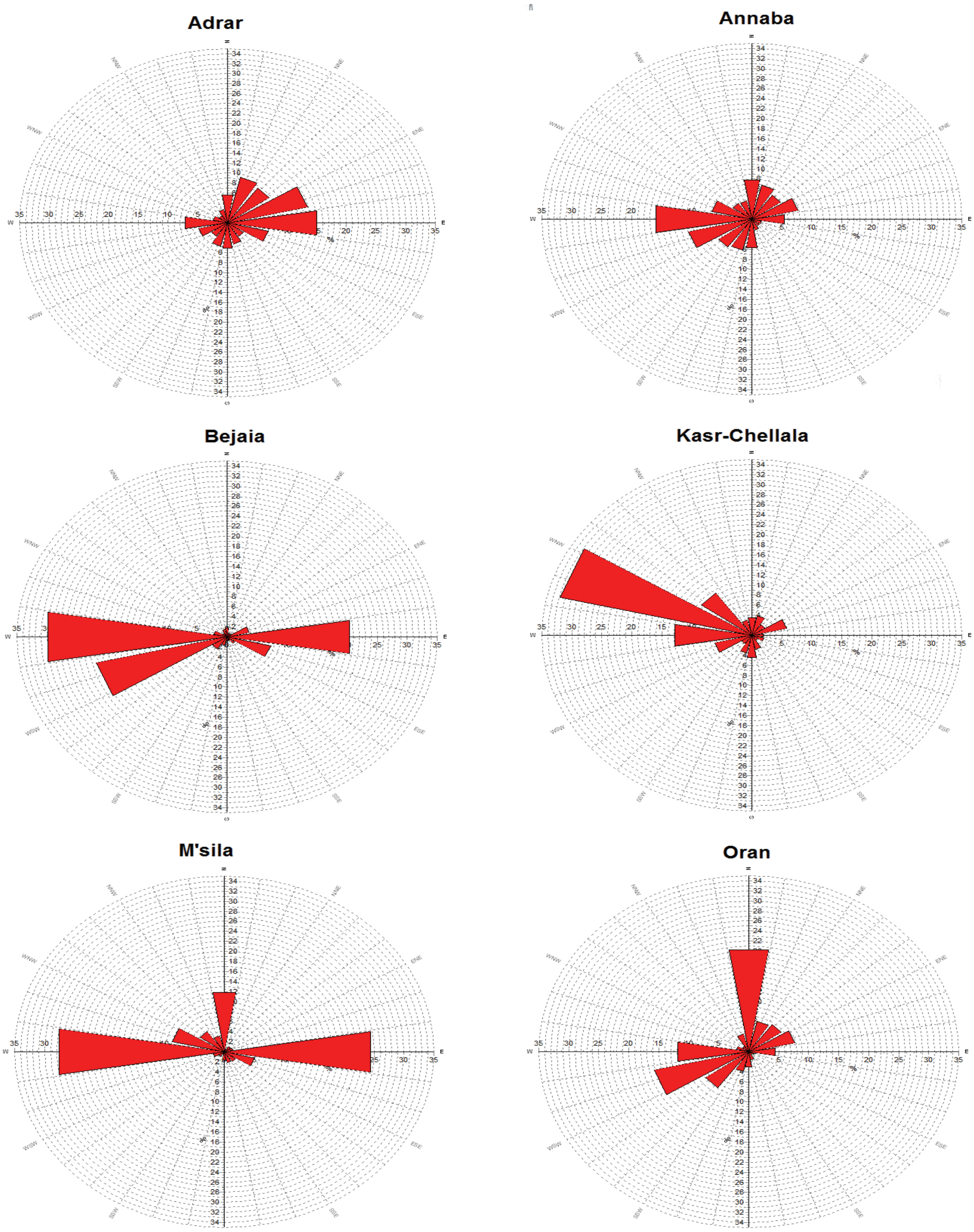

Figure 4. The wind roses for studied sites at 10m height.

4.2. Wind machine performance and Annual energy production

WGT considered is composed of an electric generator mounted suitable tower, a wind turbine controller, a battery bank, an inverter and balance system. Considering such a system, annual energy production (Ep) for the potential site can be calculated using the wind speed data belongs to that site and the power curves regarding the wind turbines that selected The method of calculation requires combining the power curve of turbine considered with the wind speed data.

The capacity factors for all WGT considered in this study are summarized in Table 5, the maximum value of the capacity factor are obtained for WGT 80KW with a value between 29.41% (Annaba) and 58.55% (Adrar).The second maximum the capacity factor are obtained for WGT 150 KW Which range from 16.23% to 41.81%. The results show that Adrar and M’sila are the most favourable sites for the installation of all types of wind turbines, while Bejaia, Kasr-Chellala and Oran remain profitable in rural and remote areas. The results for Annaba are the lowest compared with the previous sites.

Concerning machines, the WGT 80KW and WGT150 are the most performed wind turbine in all studied sites

Table 5 Annual Capacity factor for study location

Location	WGT 18KW	WGT 30KW	WGT 80KW	WGT 140KW	WGT 150KW	WGT 200KW
Adrar	35.43	25.14	58.55	30.42	48.11	41.81
Annaba	12.81	6.94	29.41	12.27	20.93	16.23
Bejaia	14.35	7.25	35.36	14.38	25.21	18.77
Kasr-Chellala	22.05	15.1	36.52	19.07	30.74	26.34
M'sila	25.9	16.35	45.26	22.89	37.26	31.81
Oran	17.09	9.41	35.9	16.07	27.06	21.61

Fig. 5 has been prepared for illustration alteration of the annual energy production in the locations where used different WGT. As can be seen this figure, the values of energy produced by WGT 200KW in one year in Adrar ,Annaba, Bejaia, Kasr-Chellala, Msila and Oran ,equal to 284.35MWh,358.85MWh,358.85MWh,461.48 MWh,5557.31 MWh and 378.61MWh, respectively.
For WGT 150 KW, the values of energy produced one year range from 284 MWh (Annaba) to 632 MWh (Adrar).

The wind turbine WGT 150 KW has the second better capacity factor and the second quantity of produced energy in all studied sites

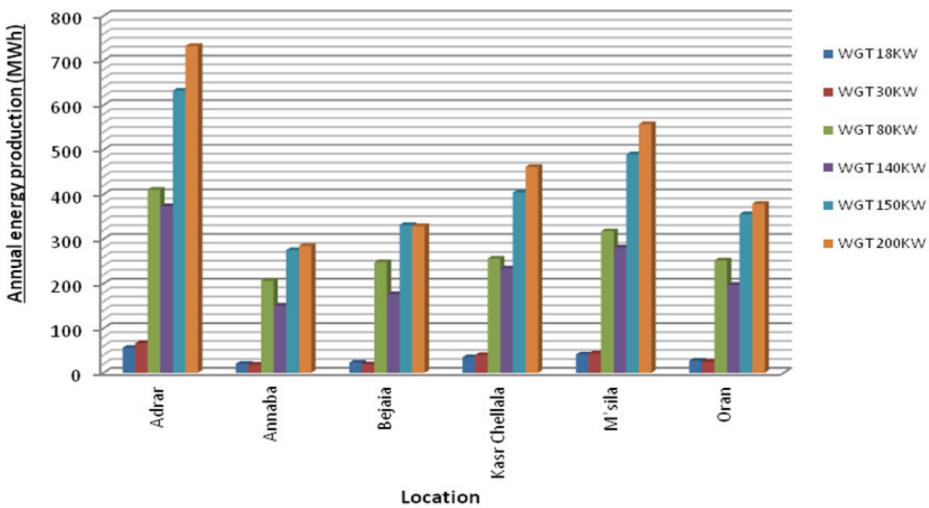

Figure 5. Annual energy production for study location.

4.3. Unite cost energy

The estimation of the costs of the kWh of energy delivered by the WGT, to be operated at the considered sites has been done under the following assumptions[7]:

- The lifetime of the WGT (n) was assumed to be 20 years.
- The discount rate (r) was taken as 8%.
- The escalation ratio of operation and maintenance (e_m) was assumed to 6%.
- The operation a maintenance cost for the first year (Com) was considered to be 25%.
- It is assumed that the WGT produces equal amount of energy output in each year during its useful lifetime.

The cost per KW of energy produced depends on the wind turbine type as well as the location wind characteristic. The results of cost analysis performed in this study for WGT 150 KW by each location are presented in Table 6.

Table 6 Cost analysis per kWh for all WGTs in different location

UCE (USD /KWh)	WGT 18KW		WGT 30KW		WGT 80KW		WGT 140KW		WGT 150 KW		WGT 200KW	
Location	min	max	min	max	min	max	min	max	min	max	min	max
Adrar	0.194	0.256	0.248	0.381	0.024	0.037	0.046	0.071	0.029	0.045	0.034	0.052
Annaba	0.536	0.707	0.900	1.379	0.212	0.326	0.114	0.176	0.067	0.103	0.087	0.133
Bejaia	0.479	0.631	0.861	1.320	0.177	0.271	0.098	0.150	0.056	0.085	0.075	0.115
Kacer_chellela	0.311	0.411	0.413	0.634	0.171	0.262	0.074	0.113	0.046	0.070	0.053	0.082
M'sila	0.265	0.350	0.382	0.586	0.138	0.212	0.061	0.094	0.038	0.058	0.044	0.068
Oran	0.402	0.530	0.663	1.017	0.174	0.267	0.087	0.134	0.052	0.080	0.065	0.100

In Adrar and M'sila , the electricity generation cost per kW from WGT 150 kW does not exceed 0.058 USD /kWh compared to price of electricity in Algeria 0.054 USD /KWh.

The minimal electricity generation cost per kW is 0.029 USD/kWh in Adrar, while its maximal value is 0.85 USD/kWh in Annaba, used wind turbine WGT 150 kW. This cost will be decreased further as the cost of wind energy systems will be lowered based on the development of wind energy technology.

5. Conclusion

This study focused on the evaluation of wind potential and the cost per KW of energy produced of six sites in Algeria (Adrar, Annaba ,Bejaia ,Kacer-Chellala, M'sila and Oran), in order to use small wind turbines, based on wind speed measurements recorded during a ten-year period, from 2001 to 2010. Wind resource analysis in the selected sites shows that Algeria has a wind energy potential that can be exploited effectively. Indeed, statistical treatment of data allowed evaluating the characteristic speeds and wind potential for each site. The results obtained show that:

- The average annual wind speeds, at 10 meters from the ground, range from 3.8 m/s (Annaba) to 6.5m/s (Adrar).
- The form parameter value k for Adrar, Bejaia ,Kaser-Chellala and M'sila account respectively 2.06,2.64,2.34and 2,26, shows that these distributions is stable, whereas the two other sites have a lower value of k, which means that winds are widely dispersed.
- The scale parameter C shows that Adrar the most windy (7.4 m/s) and the least windy is Annaba (4.3 m/s).
- The western is the prevailing wind direction for Annaba, Bejaia and M'sila which have respectively16%, 30% and 28% of episodes. However, the prevailing wind direction for Oran is the north with 20 % of episodes, the eastern sector represents 15 % of wind frequencies for Adrar and the West- North –West (WNW) directions represents 28 % of episodes for Kaser-Chellala.
- The maximum capacity factor was 56% and was recorded in Adrar, are obtained for WGT 80KW.
- The maximum estimated capacities of the yearly energy are obtained for WGT 80KW, produced at the sites of Adrar , Annaba, Bejaia, Kasr-Chellala, Msila and Oran ,equal to284.35MWh,358.85MWh,358.85MWh,461.48 MWh,5557.31 MWh and 378.61MWh, respectively
- The minimal electricity generation cost per kW is 0.029 USD/kWh in Adrar, used wind turbine WGT 150 kW, while its maximal value is 1.379 USD/kWh in Annaba, used wind turbine WGT 30 KW.
- In Adrar and M'sila , the electricity generation cost per kW from WGT 150 kW does not exceed 0.058 USD /kWh compared to price of electricity in Algeria 0.054 USD /KWh.
- The WGT 150 KW has the second better capacity factor ,the second quantity of produced energy and the cheaper unit cost in all studied sites.

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