Wind energy potential assessment of the region of Annaba- Northeast Algeria -

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Abstract—*The aim of this study is to investigate the potential of wind energy in the region of Annaba, located in the Northeast of Algeria. Eleven years (2007–2017) wind data at* $10m$*, from Algerian stations Meteorological, has been analyzed to obtain wind energy potential assessment. The two-parameter Weibull distribution has been used to determine and analyzed the wind power density and wind energy potential. Several methods are used to estimate the Weibull parameters. In this paper, the standard deviation method is used, given its robustness and reliability. On the other hand, the vertical extrapolation of the velocity is used to evaluate the power density and energy density at heights of* $30m$*, and* $60m$*. The results of this study show that this site is not a suitable location for large scale wind turbines, but for the use of off-grid electrical applications.*

Keywords: *Assessment, Wind energy, Weibull distribution, Power density, Wind energy potential.*

I. Introduction

Faced with increased energy demand caused by greater consumption, especially due to population growth and the increase of industrial sectors, sustainable energy supply remains the main requirement of modern society.

For a long time, the production of electric energy was based on fossil fuels. Unfortunately, not only is the supply of oil, coal and natural gas limited, but there are also major pollution and environmental problems associated with the use of traditional energy sources [1], [2]. All these problems have forced scientists to draw attention to clean energy sources which are both environmentally more suitable and renewable. Among renewable sources of energies, wind power is an important source of environmental-friendly energy and has become more and more important in the recent years. The use of wind energy has grown remarkably rapidly over the last 20 years, and it is now a mature, reliable and efficient technology for the production of electrical energy [3]. The positive impacts of wind energy on the mitigation of climate change as well as an opportunity to diminish energy dependency are indisputable. Wind energy helps to decrease import dependency, diversifying sources of production and contributes to a sustainable development in many countries [4]. On the other hand, since the wind energy source is inherently stochastic in nature and therefore an unreliable source of energy on its own in many places, the use of a wind turbine to produce electricity in combination with other energy resources becomes very reliable [1].

The geographical location and climate conditions of Algeria procure a great renewable energy potential and theoretically, some of the electrical energy needs can be produced by renewable energy [5], [6]. Algeria is embarking on a new sustainable energy era. The updated renewable energy program is to install renewable power of around 22000MW in 2030 for the domestic market, which represent about 37% of total energy consumption, with the maintenance of the export option as a strategic objective, if market conditions permit. [6], [7]. In this context, many renewable energy projects will be developed and realized to achieve this goal. Among these projects, there is the use of wind turbines to generate electricity.

The starting point for any wind energy project is based on the resource assessment. Over the last decade, a large number of studies related to wind potential and wind feature evaluation have been developed in many countries. An important paper for the aim of this work is by Mostafaeipour and al [1], who realized a detailed analysis of the potential of wind energy and economic evaluation in Zahedan-Iran, the effect of hub height on the wind speed. They concluded that the Proven 2.5kW model is the most economical wind turbine model. Boudia and al [6] carried out an evaluation of the wind energy potential in the northwestern Tlemcen region of Algeria. In this study, the wind potential and economic analysis of the Tlemcen area have been realized. They concluded that despite relatively low potential, this region can be adapted to wind generation. In reference [9], Yaniktepe studied the possibility of producing electric power from wind energy in Osmaniye Turkey. However, they concluded that this region may be suitable for connected electrical and mechanical applications, such as charging the battery and pumping water.

The aim of this paper is to investigate the potential of wind energy in the region of Annaba, located in the Northeast of Algeria. The rest of this paper is organized as follows. In the second section, we present the topography and the Wind energy in Algeria then, we describe the region studied in this work, as well as the data used to evaluate the wind energy potential. The Wind mathematical analysis and modeling are presented in the section III. The simulation and obtained results are shown in section IV. Finally, a conclusion is drawn in Section V.

II. Wind energy in Algeria and site description

Located south of the Mediterranean Sea and situated in the centre of North Africa between 38–35° latitude north and 8–12° longitude east, the topography of Algeria being very diversified, spread over a surface of more than 2 million km². The map of Algeria can be subdivided into several regions according to their geographical situation namely: coastline, Atlas Tellien, High plateau, North of the Sahara and the big Sahara. The geographical location and climate conditions of Algeria procure a great renewable energy potential and theoretically, some of electrical energy needs can be produced by renewable energy. During the past two decades, several studies on the wind potential in Algeria concluded that the country had significant wind energy potential at several sites Fig.1 [5], [8]. A study conducted in collaboration with the German Space Centre (DLR) enabled the identification of a progressively exploitable potential of wind energy sources in Algeria that are as 35 $TWh/year$ [8].

Annaba region is located in the Northeast of Algeria, open on the Mediterranean coast on 80 km. Located in 36.83° Latitude and 7.81° longitude, the city is about 4 m altitude with a south Mediterranean climate [15].

The wind speed data, measured at $10m$ height, is provided by the meteorological station of Annaba, for a period of eleven years (2007-2017), and will be used to evaluate the monthly and annual wind energy potential in the region.

III. Wind mathematical analysis and modeling

Knowledge of wind speed frequency distribution is very important to assess wind potential in any location. Several probability density functions (PDF) can be used to describe the frequency of

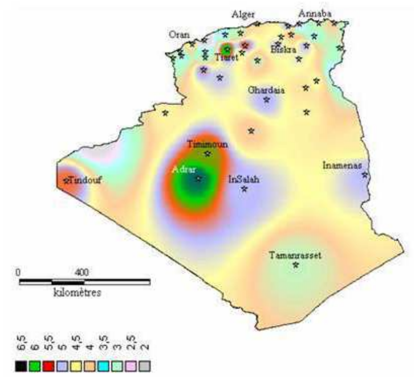

Fig. 1. Wind map evaluation in Algeria [13]

wind speed over a period of time. These probability functions include Weibull, Rayleigh, Beta, Gaussian, Gamma, and Lognormal distributions. In this work, the two-parameter Weibull distribution is employed due to its simplicity and accuracy, and is defined by [3], [4]:

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

Where $f(v)$, is the probability of getting a wind speed $v\,(m/s)$, k and c (m/s) are the Weibull shape and scale parameters respectively. Generally, the value of the dimensionless parameter k varies between 1.5 and 3. For $k = 2$ and $k = 3.6$, the Weibull distribution can be approximated by a Rayleigh and a Gaussian distributions respectively [15]. Several methods are used to determine the two parameters of the Weibull distribution, among them the standard deviation method adopted in this paper [10], [14]. Therefore, k and c can be given in terms of the mean speed $\bar{v}$ and the standard deviation σ as [1], [3]:

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1,086} \quad (2)$$

$$c = \frac{\bar{v}}{\Gamma(1+\frac{1}{k})} \quad (3)$$

Where $\Gamma(.)$ is the gamma function given by:

$$\Gamma(x) = \int_0^\infty \exp(-t) t^{X-1} dt \qquad with \qquad x > 0 \quad (4)$$

The mean wind speed and the standard deviation values are calculated using measured data:

$$\bar{v} = \frac{1}{N_d}\sum_{i=1}^{N_d} v_i \quad (5)$$

$$\sigma = \left(\frac{1}{N_d}\sum_{i=1}^{N_d}(v_i - \bar{v})^2\right)^{1/2} \quad (6)$$

Moreover, the average wind speed and the standard deviation can be related to the Weibull distribution parameters through [2], [5]:

$$\bar{v} = \int_0^\infty v f_w(v) dv = c\Gamma(1+\frac{1}{k}) \quad (7)$$

$$\sigma = c\sqrt{\Gamma(1+2/k) - \Gamma^2(1+1/k)} \quad (8)$$

III.1 Extrapolation of wind speed

It is well known that the wind blows slowly at low altitude then it increases at high altitude. In this study, the wind speed data were measured at $10m$ height. In order to evaluate the wind potential at higher elevations, a vertical extrapolation of the wind speed is carried out. Several mathematical models describing the vertical profile of the wind speed were developed. Using the Weibull distribution, the shape parameter k_h and scale parameter c_h at a desired altitude h can be given by [7], [11], [12]:

$$k_h = \frac{k_o}{[1 - 0.088 \ln(h/10)]} \quad (9)$$

$$c_h = c_o (h/10)^n \quad (10)$$

$$n = [0.37 - 0.088 \ln(c_o)] \quad (11)$$

Where k_o and c_o are the Weibull parameters at $10m$ height and n is the power law exponent.

III.2 Wind power density classification

To classify wind energy in the region under study, several approaches are proposed, among them, the PNL (laboratory Battelle-Pacific Northwest Laboratory) classification, which divides the wind energy in seven classes, ranging from 1 (lowest) to 7 (the highest), for three different heights namely $10m$, $30m$ and $50m$ [1]. Each class is represented by a wind power density range (W/m^2) or an equivalent average wind speed range (m/s). Table3 reports the wind power PNL classification at $10m$ only.

III.3 Wind power and wind energy densities estimation

To evaluate the wind energy potential in a given region, it is required to estimate the power density in the site. Generally, the wind power blowing at speed $v(m/s)$ through a blade sweep area S is proportional to the cube of the wind velocity [4], [9]:

$$P_v = \frac{1}{2} S\rho v^3 \quad (12)$$

Where $\rho = 1.225\, kg/m^3$ is the air density at the sea level [9].

Using the Weibull parameters, the wind power density (W/m^2) may be given by [5], [9]:

$$P_w = \frac{P_v}{S} = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) \quad (13)$$

In addition, the wind energy density for a specific duration T, can be calculated in terms of the power density:

$$E_w = \frac{E}{S} = \frac{P_v}{S} = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) T \quad (14)$$

IV. Results and discussion

In this study, wind speed data for the eleven years from 2007 to 2017 are analyzed. Using the mathematical equations developed in section III, the monthly and yearly Weibull parameters k and c (m/s), the average wind speed $v(m/s)$, the power density $P_w\left(W/m^2\right)$ and the energy density are calculated.

Fig.2 illustrates the histogram of the wind speed data for the eleven years and the corresponding estimated Weibull frequency distrubution. It can be easily noticed that the Weibull PDF shows a good fit to the measured wind speed data. It can observed that the maximum probability of occurrence of the site is slightly greater than 0.2. and the wind speed covers a variation range of $\left[0-10m/s\right]$.

Table.1 and Table .2 illustrate the average speeds and standard deviations of the eleven years considered in this paper. One can see that over months and years, the wind speed is relatively low and constant lying between $2.393m/s$ and $4.826m/s$.

It is noteworthy that the maximum average speed is about $4.826m/s$ achieved in February 2015. Therefore, from the recorded data, the region under study belongs to class 1 according to PNL classification as reported in Table 3. Hence, this area may not be suitable for large-scale electricity generation throughout the year.

Table- 1: Monthly mean wind speed

Months	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Whole years
Jan	**2.393**	2.589	3.244	3.757	2.896	3.772	3.935	3.496	4.423	3.673	3.963	3.467
Feb	3.598	2.425	3.619	3.642	3.833	4.175	4.125	3.426	**4.826**	4.099	3.068	3.712
Mar	4.057	3.468	3.073	3.343	3.453	3.000	3.692	3.831	4.222	4.360	3.535	3.639
Apr	3.125	3.610	3.212	3.298	3.305	3.133	3.657	3.646	3.563	3.746	3.417	3.428
May	3.341	3.295	2.911	3.504	3.239	3.306	3.766	3.613	3.835	3.774	3.531	3.465
Jun	3.546	3.471	3.395	3.618	3.373	3.128	4.104	4.059	4.264	3.738	3.513	3.655
Jul	3.806	3.788	3.279	3.707	3.718	3.713	4.771	4.182	4.020	3.749	3.931	3.879
Aug	3.634	3.700	3.480	3.624	3.402	3.193	4.371	3.830	3.875	3.802	3.835	3.704
Sep	3.373	3.536	3.026	3.460	3.441	3.137	3.088	3.575	4.060	3.167	3.471	3.394
Oct	3.124	2.950	3.456	3.355	3.395	2.608	2.996	3.688	3.735	2.761	3.148	3.201
Nov	3.058	3.126	2.731	3.393	2.730	2.542	4.139	3.569	3.763	2.929	3.621	3.236
Dec	3.549	2.968	2.890	3.470	3.744	3.269	3.057	4.790	2.706	2.333	3.331	3.282
Yearly	3.384	3.244	3.193	3.514	3.377	3.248	3.808	3.809	3.941	3.511	3.530	3.505

Table -2: Monthly standard deviations

Months	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Whole years
Jan	1.480	1.588	2.555	2.487	1.772	2.197	1.897	2.143	2.201	2.280	2.252	2.077
Feb	2.311	1.540	2.160	2.276	2.372	2.326	2.373	1.680	2.604	1.975	2.783	2.218
Mar	2.823	2.261	2.305	1.990	2.235	2.191	2.136	2.043	2.568	2.301	2.344	2.291
Apr	1.986	2.080	2.008	2.252	2.253	1.986	2.165	2.402	1.978	2.047	2.222	2.125
May	1.855	2.370	1.746	2.149	2.100	2.287	2.430	2.346	1.926	2.269	2.607	2.189
Jun	2.421	2.680	2.210	2.294	2.336	2.339	2.699	2.456	2.225	2.352	2.439	2.405
Jul	2.606	2.275	2.164	2.476	2.390	2.632	3.562	2.768	2.574	2.547	2.722	2.611
Aug	2.587	2.417	2.341	2.535	2.493	2.643	3.067	2.797	2.277	2.684	2.572	2.583
Sep	2.203	2.147	1.954	2.360	2.288	2.288	2.063	2.249	2.020	2.172	2.404	2.195
Oct	2.155	1.722	2.073	2.078	2.059	1.943	1.964	1.866	1.992	2.077	1.928	1.987
Nov	1.530	2.061	1.701	1.985	1.867	1.667	2.114	2.187	2.240	2.056	2.144	1.959
Dec	2.311	2.032	1.834	2.007	2.243	1.836	1.681	2.493	1.130	1.671	2.155	1.945
Yearly	2.189	2.098	2.088	2.241	2.201	2.195	2.346	2.286	2.145	2.203	2.381	2.215

The monthly and yearly Weibull parameters (k, c), the power density and the energy density at $10m$ are given in Table. 4 and 5 respectively. It should be mentioned that the monthly values were obtained on the basis of the average of all years.

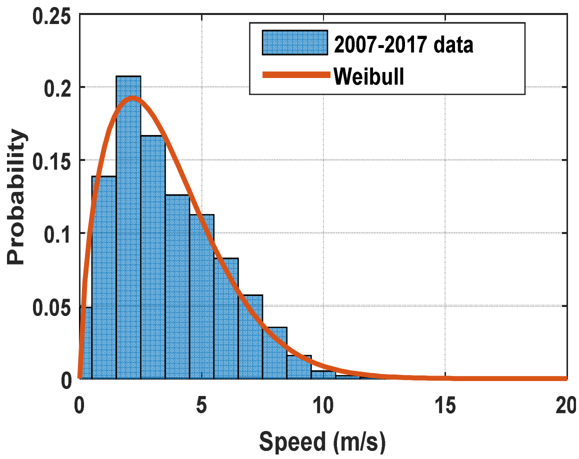

Fig.2. Weibull PDF curve against years 2007-2017 data

Table-3: PNL classification [1]

Wind power class	10 m wind power (W/m^2)	10 m speed (m/s)
1	≤ 100	≤ 4.4
2	≤ 150	≤ 5.1
3	≤ 200	≤ 5.6
4	≤ 250	≤ 6.0
5	≤ 300	≤ 6.4
6	≤ 400	≤ 7.0
7	≤ 1000	≤ 9.4

Table-4: Monthly Weibull parameters (k. c), power density and energy density at 10 m

Month	k	c (m/s)	P(W/m^2)	E(kWh/m^2)
Jan	1.756	3.884	55.780	41.501
Feb	1.774	4.145	66.896	44.954
Mar	1.662	4.026	67.303	50.073
Apr	1.686	3.831	56.743	40.855
May	1.665	3.904	61.240	45.562
Jun	1.582	4.053	74.307	**53.501**
Jul	1.547	4.300	92.172	**68.576**
Aug	1.485	4.084	85.007	**63.245**
Sep	1.612	3.783	58.566	42.167
Oct	1.685	3.546	45.019	33.494
Nov	1.729	3.654	47.503	34.202
Dec	1.794	3.660	45.360	33.748

From the obtained results in Table 4, it is important to note the monthly wind energy density values vary from $33.494 kWh./m^2$ to $68.576 kWh./m^2$ with the relatively maximum values attained in June, July and August. Moreover, from Table 5, the average yearly wind energy density is nearly $543 kWh./m^2$.

Table- 5: Yearly Weibull parameters (k. c), power density and energy density at 10 m

Year	k	c (m/s)	P(W/m^2)	E(kWh/m^2)
2007	1.632	3.769	56.795	497.520
2008	1.619	3.614	50.703	444.156
2009	1.599	3.557	**49.347**	**432.278**
2010	1.639	3.916	63.297	554.478
2011	1.596	3.763	58.573	513.098
2012	1.543	3.620	55.217	483.698
2013	1.730	4.244	74.333	**651.158**
2014	1.767	4.244	72.177	**632.269**
2015	1.974	4.391	69.915	**612.459**
2016	1.664	3.912	61.631	539.884
2017	1.549	3.934	70.393	616.645

In addition, the wind power density can be estimated at different heights, by using Eqs (9)-(11). Figs. 3-5 show the monthly extrapolation of mean wind speed, power density and energy density respectively, at $10m$, $30m$ and $60m$ height respectively. It can be noticed that at 60m height, the average speed over the months is practically greater than 5m/s resulting in relatively significant wind energy density values between $108 kWh./m^2$ and $195 kWh./m^2$.

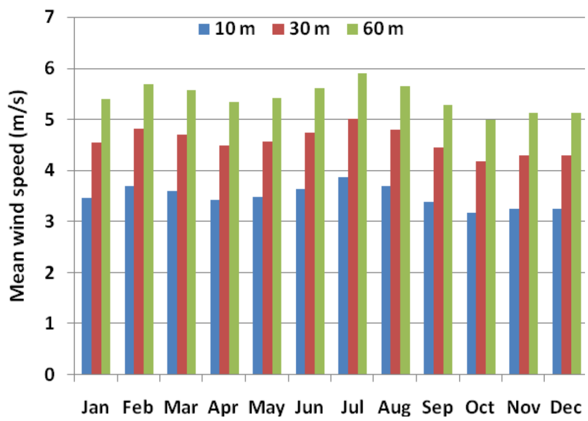

Fig. 3. Monthly extrapolation of mean wind speed

V. Conclusion

In this study, the wind energy potential analysis for the region of Annaba, in the northeast of Algeria was examined. Based on Weibull function, the statistical analysis at $10m$, above ground at the meteorological station, has confirmed that Annaba has a low wind potential. Making it not suitable for grid connected electricity generation. However, an extrapolation at 60*m* hub height has shown that this region could be more profitable for off-grid electrical applications such as lighting and water pumping.

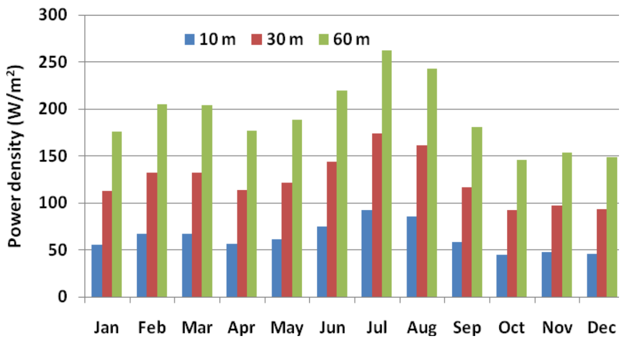

Fig. 4. Monthly extrapolation of Power density

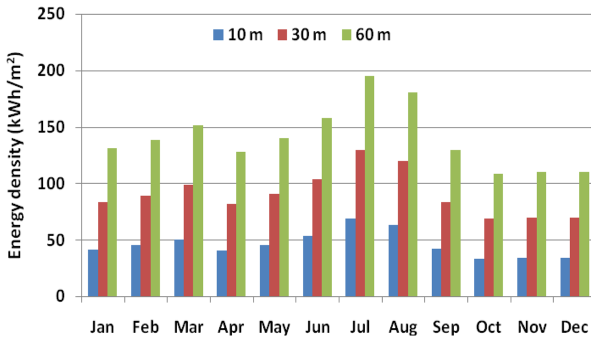

Fig. 5. Monthly extrapolation of Energy density

References

[1] A. Mostafaeipour, M. Jadidi, K. Mohammadi, A Sedaghat, " An analysis of wind energy potential and economic evaluation in Zahedan, Iran," Renewable and Sustainable Energy Reviews 30, pp. 641–650, 2014.

[2] B. Belabes, A. Youcefi, O. Guerri, M. Djamai, A. Kaabeche, "Evaluation of wind energy potential and estimation of cost using wind energy turbines for electricity generation in north of Algeria," Renewable and Sustainable Energy Reviews 51, pp. 1245–1255, 2015.

[3] A. Ouammia, H. Dagdougui, R. Sacile, A. Mimet, "Monthly and seasonal assessment of wind energy characteristics at four monitored locations in Liguria region (Italy)," Renewable and Sustainable Energy Reviews 14, pp. 1959–1968, 2010.

[4] A. Mostafaeipour, "Productivity and development issues of global wind turbine industry", Renewable and Sustainable Energy Reviews 14, pp. 1048–1058, 2010.

[5] S.M. Boudia, O. Guerr, "Investigation of wind power potential at Oran, northwest of Algeria," Energy Conversion and Management 105, pp. 81–92, 2015.

[6] S.M. Boudia, S. Berrached, S. Bourib," On the use of wind energy at Tlemcen, North-western region of Algeria," Science Direct, Energy Procedia 93, pp. 141 – 145, 2016.

[7] S. Diaf, G.Notton, "Technical and economic analysis of large-scale wind energy conversion systems in Algeria", Renewable and Sustainable Energy Reviews 1, pp. 37–51, 2013.

[8] A. B. Stambouli, "Algerian renewable energy assessment: The challenge of sustainability," Energy Policy 39, pp. 4507–4519, 2011.

[9] B. Yaniktepe, T.Koroglu, M.M. Savrun, "Investigation of wind characteristics and wind energy potential in Osmaniye, Turkey," Renewable and Sustainable Energy Reviews 21, pp. 703–711, 2013.

[10] T. P. Chang , " Performance comparison of six numerical methods in estimating Weibull parameters for wind energy application," Applied Energy 88, pp. 272–282, 2011.

[11] **A. S**. Mikhail, "Height Extrapolation of Wind Data," Journal of Solar Energy Engineering, Vol. 107, pp. 10-14, February 1985.

[12] C.G. Justus, A. Mikhail, "Height variation of wind speed and wind distributions statistics," Geophys Res Lett 3(5), pp. 261–264, 1976.

[13] https://www.cder.dz (accessed 25.07.2018).

[14] K. Mohammadi, A. Mostafaeipour**,** " Using different methods for comprehensive study of wind turbine utilization in Zarrineh, Iran," Energy Conversion and Management 65, pp. 463–470, 2013.

[15] F. Chellali a, A. Khellafb, A. Belouchranic, R. Khannichea, "A comparison between wind speed distributions derived from the maximum entropy principle and Weibull distribution. Case of study six regions of Algeria," Renewable and Sustainable Energy Reviews 16, pp. 379–385, 2012.