Estimation of wind energy potential and Weibull parameter extrapolation of the city of Annaba, Algeria

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Abstract— **This work examines the assessment of wind energy capacity in the region of Annaba situated in Northeast of Algeria. The variation of the wind speed in terms of the altitude is required to evaluate the wind resources and predict the energy production of a given wind farm. Generally, the wind speed data, measured at a reference height, are extrapolated to the desired hub height using several empirical laws. In this paper, the power law method, suggested by Justus and Mikhail, is employed to extrapolate the Weibull parameters, using wind time series data obtained from the meteorological stations. Thus, the vertical extrapolated velocity is, then, used to evaluate the power and energy densities at heights of 30m and 60m. The obtained simulation results show that the considered site may be appropriate for small off-grid applications, but not for large wind turbines.**

Keywords— Weibull distribution, Weibull parameters, wind speed, wind energy potential, wind speed extrapolation.

I. INTRODUCTION

Our planet is more and more affected by various industrial activities causing climate change and pollution. The main human activity responsible for such environmental degradation is combustion, including fossil fuels: oil, coal and gas. In order not to further degrade the planet, many countries have agreed on different actions reducing the use of conventional energies that emit greenhouse gases (such as coal or oil) and employ renewable energies (wind and solar energies) instead [1]. In recent decades, many countries have established strategies to promote new renewable and clean energy resources to meet their energy needs and thus reduce the use of fuels.

Wind energy is one of the clean and inexhaustible resources developed to meet a portion of the energy demand of many countries. The use of wind energy has grown rapidly and considerably over the last twenty years, becoming a well developed and efficient technology for electrical energy generation [2]. Besides, this kind of energy has positive impacts on climate change mitigation and energy dependency, as well as it contributes a lot to a sustainable development in many countries [3].

Algeria has an important renewable energy potential due to its geographical position and appropriate weather conditions, and, hence, a part of the electrical energy demand can be generated by renewable energies [4], [5]. Recently, Algeria is entering a new renewable energy historical period where the last energy installation program, amounts, by 2030, to nearly 40% of the total energy consumption for the domestic market. To achieve this goal, several projects based on renewable energy are to be planned and accomplished, including the use of wind turbines for electricity production.

Wind resource assessment is the key success to any wind project accomplishment, which, necessarily, involves extrapolation of wind speed to boost wind turbine efficiency.

Commonly, wind speeds are evaluated at *10 m* height from the ground. Wind speed measurements, that are either short-term (from 10 minutes up to one hour) or long-term (monthly or yearly), depend strongly on the height from the ground and the type of the terrain (uniform or complex). Generally, low wind speed is detected at low altitude, while it rises at higher elevation. Accordingly, since wind turbine heights are often greater than 10 m, the wind speed at turbine hub elevations should be estimated using extrapolation techniques. Various models applied in wind speed data extrapolation at different heights, in the short and long term, have been proposed [2].

Over flat ground, the extrapolation of short duration wind speeds, may be well described by the Monin-Obukhov similarity theory [2]. Long-term average wind parameters are estimated using the wind speed distribution parameters and wind speed mean values computed over a period of many hours.

Over the last few decades, different studies relevant to wind potential evaluation have been conducted in several regions throughout the world. Boudia et al. [4] carried out an evaluation of the wind energy resources in Oran situated in the northwest of Algeria. They concluded that wind turbines with hub height of about 90 meters and a nominal capacity of 2.5 MW may be recommended for a wind farm construction in the considered site for electric power generation. Yaniktepe et. al. [6] investigated the possibility of producing electricity from wind turbines in Osmaniye, Turkey. It has been concluded that this region may be suitable for off-grid electrical and mechanical systems, including battery chargers and water pumps.

In [7], Mostafaeipour et al., realized a detailed analysis of wind energy resources for the region of Zahedan in Iran and its economic impact. It has been shown that a 2.5kW wind turbine is the most suitable and economical for electricity generation in the considered region.

The present paper explores the wind power capacity of the city of Annaba in Algeria. The investigation, based on Weibull parameters, is carried out through extrapolation using the power law method proposed by Justus and Mikhail [8] and employing eleven years (2007-2017) of wind time series data gathered from Algerian meteorological stations.

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The remaining of the article is structured as follows. Section 2 gives a description of the topography, the wind energy in Algeria, the region considered in this work, and the data utilized to evaluate the wind energy capacity. The wind speed mathematical concepts and modeling are exposed in section 3. Section 4 explains the simulation and provides the obtained results. Finally, section 5 presents the conclusions.

II. WIND ENERGY IN ALGERIA AND SITE DESCRIPTION

Located south of the Mediterranean Sea in North Africa, 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. Algeria geographical situation and weather conditions provide a considerable renewable energy resources. 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 [4], [9]. A joint study with the German Space Centre (DLR) identified a progressive exploitable resources of wind energy in Algeria that amount to nearly $35TWh/year$ [9].

Annaba is located in the Northeast of Algeria, and it extends for some 80 km along the Mediterranean coast. Located in 36.83° Latitude and 7.81° longitude, the city is about 4 m altitude with a south Mediterranean climate [10].

The wind speed data, measured at 1(height, is obtained from 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.

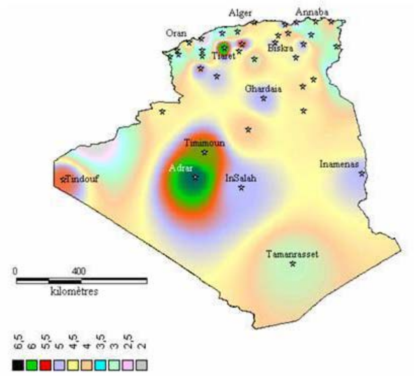

Fig. 1. Wind map evaluation in Algeria [11]

III. WIND MATHEMATICAL ANALYSIS AND MODELING

The distribution of wind speed frequency is essential to assess wind energy resources in any location. Several probability density functions (PDF), such as Weibull, Rayleigh, Beta, Gaussian, Gamma, and Lognormal, may be adopted to describe the wind speed frequency over a period of time. Owing to its simplicity and accuracy, we have employed, in this paper, the two-parameter Weibull distribution described by [2], [3]:

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

Where $f(v)$, is the probability of getting a wind speed $v\ (m/s)$, k and $c\ (m/s)$ represent 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 distribution of Weibull may be represented by a Rayleigh and a Gaussian distributions respectively [10]. Several methods are used to determine the two parameters of the Weibull distribution, among them the standard deviation method adopted in this paper [12], [13]. Therefore, k and c can be given in terms of the mean speed $\bar{v}$ and the standard deviation σ as [2], [14]:

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

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

Where $\Gamma(.)$ is the gamma function defined as:

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

The average 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 wind speed mean value and its standard deviation can be related to the Weibull distribution parameters through [4], [15]:

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

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

A. *Extrapolation of wind speed*

It is well known that the wind blows slowly at low altitude then it increases at high altitude. In order to assess the wind capacity at higher elevations, a vertical extrapolation is carried out using the wind time series data measured at $10m$ height. Various numerical models describing the wind speed vertical profile were developed. Using the distribution of Weibull, the shape parameter k_h and scale parameter c_h at a given altitude h can be given by [8], [14], [15], [16]:

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

$$c_h = c_o(h/10)^n \tag{10}$$

$$n = [0.37 - 0.088 \ln(c_o)] \tag{11}$$

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

B. *Classification of wind energy and power densities*

For wind energy/power classification in a given region, several approaches are proposed, among them, the PNL (laboratory Battelle-Pacific Northwest Laboratory) classification. Such arrangement divides the wind energy in seven categories, classified from 1 up to 7, depending upon the generated wind power, for three different heights namely $10m$, $30m$ and $50m$ [1]. Each class is represented by an interval of wind power density values (W/m^2) or an equivalent average wind speed range (m/s). Table1 reports the wind power PNL classification at $10m$ only.

C. *Wind power and wind energy densities estimation*

To estimate the wind energy potential for a certain region, it is required to determine the power density in the site. Generally, the wind power blowing at speed $v(m/s)$ through a swept area S is usually proportional the wind velocity cubed [3], [6]:

$$P_v = \frac{1}{2} S \rho v^3 \tag{12}$$

Where $\rho = 1.225\, kg/m^3$ is the density of air at the sea level [7]. Using the Weibull parameters, the wind power density (W/m^2) can be defined by [4], [7]:

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

TABLE 1. PNL CLASSIFICATION

Wind power class	10 m wind power (W/m²)	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

IV. RESULTS AND DISCUSSION

This article is intended to analyze the wind speed data for the eleven years from 2007 to 2017 in the city of Annaba. 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 $P_w(W/m^2)$ and the energy density $E_w(kWh/m^2)$ are calculated. Fig.2 shows the histogram of the wind speed data for the eleven years and the corresponding estimated Weibull frequency. It is noticeable that the Weibull PDF fits the measured wind speed well. 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 $[0-10m/s]$.

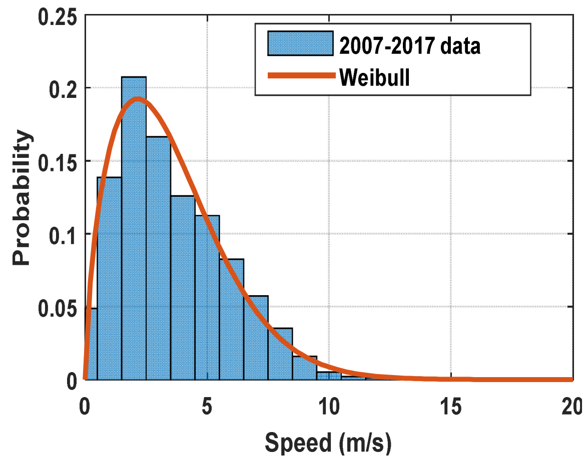

Fig. 2. Weibull PDF curve against years 2007-2017 data.

Table.2. illustrate the annual Weibull coefficients (*k, c*), power density and energy density of the eleven years considered in this work. One can see that over years, the energy density is relatively low and constant lying between $432.278(kWh/m^2)$ and 651.158 $(\boldsymbol{kWh/m^2})$.

TABLE 2. YEARLY WEIBULL PARAMETERS (K, C), POWER DENSITY AND ENERGY DENSITY

Year	k	c (m/s)	P(W/m2)	E(kWh/m2)
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

The extrapolation of the mean wind speed, the power density and the energy density at $10m$, $30m$ and $60m$ height respectively, are given in Table. 3. From the obtained results, It is noteworthy that the yearly maximum average speed at 10m is about $3.89m/s$ achieved in 2015.
Hence, this region may not be appropriate for large amount electricity production throughout the year.

It is important to note that the yearly minimum values recorded at 10, 30 and 60 m are 432.28, 870.57 and $1364.27 kWh./m^2$ respectively, achieved in 2009, whereas the maximum values recorded at 10, 30 and 60 m are 651.16, 1273.09 and $1956.70\, kWh./m^2$ respectively, achieved in 2013.

Besides, using Eqs (9)-(11), estimates of the density of the wind power could be obtained at different heights. Figs. 3-5 depict the extrapolation of the annual 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 $1300 kWh./m^2$ and $2000 kWh./m^2$.

V. CONCLUSION

The present study aimed to investigate the wind power capacity for the region of Annaba, in the northeast of Algeria. Using the wind speed data from Algerian meteorological stations and based on Weibull function analysis, at $10m$ above ground, it has been confirmed that the region of Annaba has a relatively low wind potential, making it inappropriate for grid connected electricity generation. Nevertheless, through extrapolation at 60 m height, the obtained simulation results have shown that the region under consideration could be more suitable for small off-grid electrical applications.

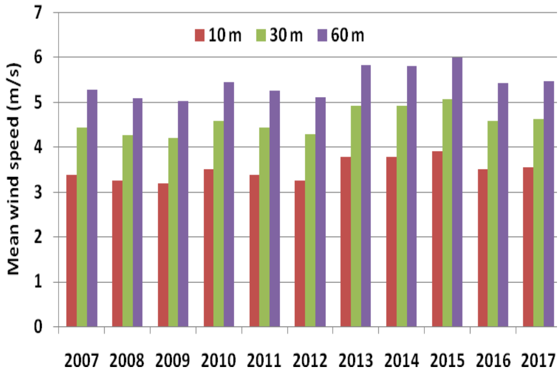

Fig. 3. Yearly extrapolation of mean wind speed

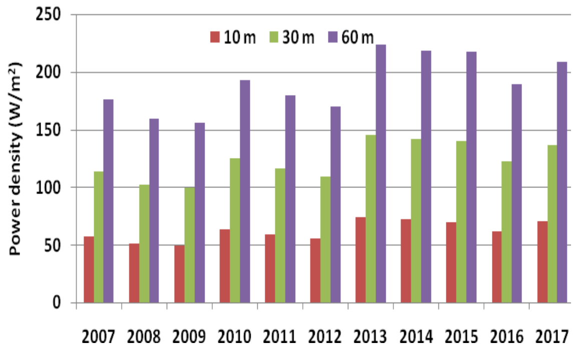

Fig. 4. Yearly extrapolation of Power density

TABLE 3. YEARLY MEAN WIND SPEEDS, POWER DENSITY AND ENERGY DENSITY

	Average wind speed (m/s)			*Power density (W/m^2)*			*Energy density (kWh/m^2)*		
Year	10 m	30 m	60 m	10 m	30 m	60 m	10 m	30 m	60 m
2007	3.37	4.43	5.26	56.79	113.14	176.06	497.52	991.13	1542.28
2008	3.24	4.26	5.08	50.70	102.01	159.75	444.16	893.62	1399.37
2009	3.19	4.20	5.01	49.35	99.38	155.74	**432.28**	**870.57**	**1364.27**
2010	3.50	4.58	5.43	63.30	124.85	193.05	554.48	1093.66	1691.11
2011	3.37	4.42	5.26	58.57	116.00	179.86	513.10	1016.12	1575.60
2012	3.26	4.28	5.10	55.22	109.47	169.92	483.70	958.98	1488.52
2013	3.78	4.92	5.81	74.33	145.33	223.37	**651.16**	**1273.09**	**1956.70**
2014	3.78	4.91	5.81	72.18	141.87	218.75	632.27	1242.78	1916.24
2015	3.89	5.06	5.98	69.92	139.53	217.02	612.46	1222.26	1901.06
2016	3.50	4.57	5.43	61.63	122.11	189.32	539.88	1069.67	1658.49
2017	3.54	4.61	5.46	70.39	136.40	208.67	616.65	1194.86	1827.97

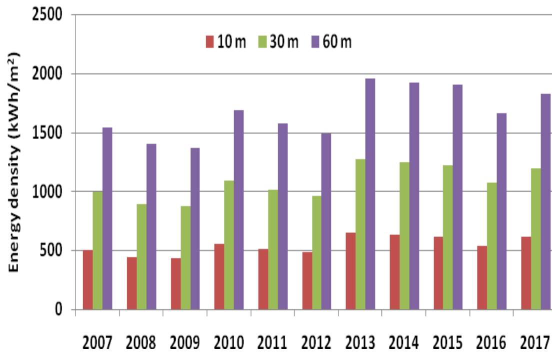

Fig. 5. Yearly extrapolation of Energy density

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