Research in Marine Sciences
Volume 3, Issue 4, 2018
Pages 401 - 414

Assessment of wind energy potential in Lebanon

G. Al Zohbi[1,*], P. Hendrick[2], and P. Bouillard[1]

[1]Building, Architecture and Town Planning, BATir, (CP 194/2), Avenue F.D. Roosevelt 50, Bruxelles, 1050, Belgium

[2]Aéro Service-Thermo-Mécanique, (CP 165/41), Avenue F.D. Roosevelt 50, Bruxelles, 1050, Belgium

Abstract

In this study, wind characteristics are analyzed using data collected wind speed for five weather stations in Lebanon and available for at least one year (2 years for Klaiaat, 10 years for Les Cedres, 7 years for Daher El Baydar, 2 years for Quaraoun, and 1 year for Marjyoun). The Weibull distribution is used to model the wind speed at these five locations in Lebanon. Shape parameters and scale were estimated using four methods, the variability of the method, the method of standard deviation, the method of power density and the Moroccan method. The purpose of this article is to compare the methods of assessment of wind energy potential, as well as evaluation of the power density at different altitudes. It was observed that the estimates using the method of power density gave the best overall fit of the data distribution of the wind. Shape parameters and scale vary considerably over a month. The annual variation of the power density varies between 2397 W/m^2 and 784 W/m^2 at Daher El Baydar and Les Cedres for the maximum and minimum values. The extrapolation of the wind speed and the Weibull parameters increases with altitude and thus the power density increases.

Keywords: Weibull parameters; Power density; Moroccan method; RMSE; R^2; Extrapolation.

1. Introduction

Wind energy is at the heart of the news. It is nowadays the fastest growing energy source on a global scale. Thanks to the decisive improvement of technologies over the past 30 years, wind power generation has reached a high level of technological maturity and industrial reliability (De Herde *et al*., 2006).

In Lebanon, electric power is provided by the production of thermal and hydraulic power plants and by importing from Egypt and Syria. Production is mainly done using fossil fuels (Bassil, 2010). Demand still exceeds supply and outages are common in peak periods (Tannous *et al*., 2010). The demand for electricity is also constant (Figure 1). In 2009, at the Copenhagen summit, Lebanon committed to produce 12%

* Corresponding Author: galzohbi@ulb.ac.be

of its energy from renewable sources by 2020 (Hamdan, 2011). It is therefore urgent for Lebanon to find a solution to cover demand with a clean source of energy.

One of the examined tracks in this study is the establishment of wind energy production sites. For electricity generation, it is a clean, fuel-free and renewable source of energy. The most accurate method for calculating shape and scale parameters is determined. The power density for five sites is estimated, as well as the power density for different heights of the wind turbine mast.

2. Data

2.1. Wind data

The data from in this study come from the meteorological service in Lebanon. The measurements of the wind speed are made at 10m height. The system used for measuring wind speed is 'Auria E' which is a data acquisition system, commonly used by Météo France (Hassan, 2011). This recorder is usually used in combination with an anemometer and wind vane. The geographical coordinates of the sites are given in Table 1. Table 2 gives the long-term measured wind speed distribution for these five stations. The average monthly wind speed for each site is shown in Figure 2.

3. Methods

In order to evaluate the potential of a site's wind energy, it is important to express the frequency distribution of the wind speed. The distribution of Weibull has been widely used, accepted, and recommended in the literature for expressing the frequency distribution of wind speed, since it gives a good agreement with Darwish experimental data (Darwish and Sayigh, 1988). The probability density function of Weibull is given by (Justus *et al*., 1978) with:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} e^{\left(-\left(\frac{v}{c}\right)\right)^{k}} \qquad (1)$$

where, u is wind speed (m/s), k is a dimensionless form factor that characterizes the frequency distribution and c is the scale factor that has the dimension of velocity. One of the important properties of the Weibull distribution which makes it so useful for wind turbine applications is that once these parameters are estimated at a

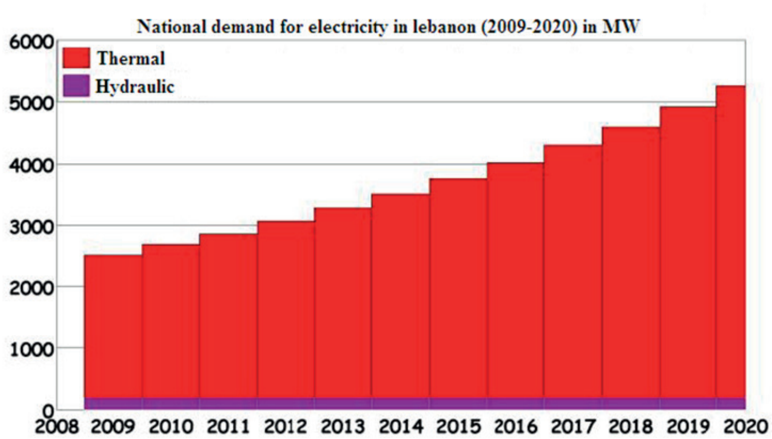

Figure 1. Evolution of electricity demand in Lebanon (Bassil, 2010)

Table 1. Geographical coordinates of selected sites (Hassan, 2011)

Station	Horizontally (m)	Vertically (m)	Altitude (m)	Data provided
Daher el Baydar	706,366	3,682,611	1,524	Nov.1999-Jan.2010
Klaiaat Akkar	78,097	3,793,722	5	Jan.2008-Jan.2010
Les Cedres	774,278	3,823,977	1,916	Jan.1999-Jul.2008
Marjyoun	749,026	3,715,206	760	Mar.2009-Feb.2010
Quaraoun	738,724	3,714,557	855	Sep.2007-Jan.2010

Coordinate System is UTM Zone 36S, Reference WGS84

Table 2.Measured distribution of wind speed

Vitesse (m/s)	Klaiaat	Marjyoun	Les cedres	Quaraoun	D.El Baydar
0	0.0134	0.000	0.002	0.003	0.000
1	0.109	0.033	0.035	0.062	0.021
2	0.344	0.155	0.212	0.228	0.089
3	0492	0.324	0.527	0.422	0.191
4	0.614	0.485	0.766	0.624	0.325
5	0.719	0.623	0.866	0.791	0.484
6	0.794	0.749	0.918	0.906	0.639
7	0.853	0.842	0.953	0.967	0.767
8	0.894	0.919	0.971	0.987	0.855
9	0.922	0.967	0.984	0.995	0.908
10	0.943	0.988	0.991	0.998	0.940
11	0.962	0.997	0.995	0.999	0.962
12	0.980	0.999	0.997	1.000	0.976
13	0.992	1.000	0.999		0.983
14	0.996		1.000		1.000
15	0.998				
16	0.999				
17	0.999				
18	1.000				

This data was provided by Dr. Riad Al Khodari, Head of the Meteorological Service of Lebanon, 14/09/2012

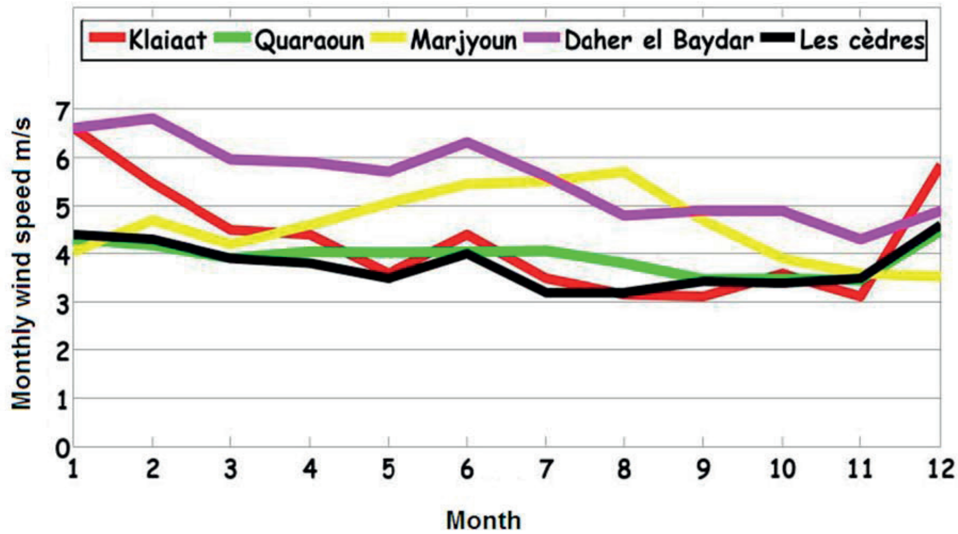

Figure 2. Monthly wind speed for the five sites (Hassan, 2011)

height, it is possible to adjust them to different heights.

A review of the literature for this study shows that for most wind conditions around the world, the form factor k varies between 1.2 and 2.75 (Justus *et al*., 1978). The distribution function is given by Justus *et al*. (1978):

$$F(v) = \int_{-\infty}^{v} f(t) \times dt = 1 - e^{\left(-\left(\frac{v}{c}\right)\right)^{k}} \quad (2)$$

There are several methods for estimating Weibull parameters. We go here discuss four commonly used methods and the most accurate one will be used in this study.

3.1. Wind variability method

This empirical approach consists of estimating k, based on wind variability and mean wind speed (Justus *et al*., 1978).

$k = 1.05 \times v^{0.5}$ for low wind variability (3)

$k = 0.94 \times v^{0.5}$ for low wind variability (4)

$k = 0.83 \times v^{0.5}$ for low wind variability (5)

The calculation of 'c' is done from the following formula:

$$c = \frac{\bar{v}}{\Gamma\left(1 + \frac{1}{k}\right)} \quad (6)$$

which, the gamma function (Γ) defined by

$$\Gamma(v) = \int_{0}^{+\infty} t^{z-1} e^{t-1} dt \quad (7)$$

3.2. Standard deviation method

This method was suggested by Justus *et al*. (1978). If the mean speed and the standard deviation are available, the estimation of the parameters is done using the following two formulas:

$$k = \left(\frac{\sigma}{v}\right)^{-1.086}$$
$$c = \frac{\bar{v}}{\Gamma\left(1 + \frac{1}{k}\right)} \quad (8)$$

3.3 Power density method

The expression of the power density for the

Weibull distribution is given by following equation (Raichle and Carson, 2009):

$$P_W = \frac{1}{2}\rho \times \int_0^3 v^3 f(v)dv \quad (9)$$

where, ρ is the density of the air (kg/m^3):
The cubic average velocity is:

$$\bar{v}^3 = c^3\Gamma\left(1+\frac{1}{k}\right) \quad (10)$$

Average cubic velocity is:

$$v^3 = c^3\Gamma\left(1+\frac{3}{k}\right) \quad (11)$$

We define the energy model factor:

$$E_{pf} = \frac{v^3}{\bar{v}^2} \quad (12)$$

The value of k is determined using E_{pf}

$$k = 1+\frac{3.69}{E_{pf}^2} \qquad c = \frac{\bar{v}}{\Gamma(1+1/k)} \quad (13)$$

3.4. Moroccan method

This method was used during the evaluation of the wind potential in Morocco (Mabchour, 1999). The following formula determines k:

$$k = 1+(0.483\times(\bar{v}-2))^{0.51} \quad (14)$$

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

In order to test the various methods, besides calculating the parameters of statistical analysis, the Equation (15) (Akpinar and Akpinar, 2007; Ben Amar *et al*., 2008) determines the coefficient of determination R:

$$R^2 = 1-\frac{\sum_{i=1}^{N}(y_i-x_i)^2}{\sum_{i=1}^{N}(y_i-\bar{y})} \quad (15)$$

and the root mean squared error;

$$RMSE = \left(\frac{1}{N}\times\sum_{i=1}^{N}(y_i-x_i)^2\right)^{0.5} \quad (16)$$

where, N is the total number of intervals is the frequency of observed value, is the value frequency obtained by the Weibull distribution and is the mean value of. A model is said to be ideal, if it is characterized by a null value for RMSE and 1 for the parameter R^2.

3.5 Extrapolation of Wind Speed and Weibull Parameters

In general, wind speed measurements are made at 10m altitude above the surface of the earth. However, it is necessary to estimate the wind speed at different altitudes. Wind speed increases with altitude. The extrapolation of the wind speed for different altitudes is obtained by the following relation (Justus and Mikhail, 1976):

$$v = v_0 \times (z/z_0)^{\alpha} \quad (17)$$

$$\alpha = 1/\ln(z_g/r_0) \quad (18)$$

With v_0, the wind speed measured at 10 m altitude, v, the speed that must be, the exponent of power law that is depending on theαcalculated at the altitude z, surface roughness, z_g, the geometric mean of the height 0.5 (z_0*z) and r_0, the roughness of the soil. The extrapolation of Weibull parameters is obtained by the following relations (Justus and

$$k_z = \frac{k_a}{1-0.00881\times\ln(z/10)} \quad (19)$$

$$C_z = C_0\times(z/z_0)^n \quad (20)$$

$$n = \frac{0.37 - 0.088 \ln C_0}{1 - 0.00881 \times \ln(z/10)} \quad (21)$$

3.6 Assessment of the average power density of wind energy

The power density of wind energy is the most important feature of the wind. It represents the amount of energy produced by the wind. Suppose A is a cross-section through which the wind flows perpendicularly. The power of the wind is given by the following relation (Ramirez and Carta, 2005; Tar, 2008):

$$P(v) = \frac{\rho \times v^2}{2} \times v \times A \quad [W] \quad (22)$$

The ρ air density depends on the pressure (altitude), the temperature and the humidity. It is assumed to be constant since its variation does not affect the wind resource calculation in a significant way (Ramirez and Carta, 2005, Tar, 2008). In this study, the average air density is used according to its altitude for each site. The distribution density of wind energy gives the distribution of energy wind turbine at different wind speeds. It is obtained by multiplying the wind power density by the probability of each wind speed as follows:

$$\frac{P(v)}{A} f(v,k,c) = \frac{1}{2} \times \overline{\rho} \times v^3 \times f(v,k,c) \quad [W/m^3 s] \quad (23)$$

By integrating Equation (23) for the study period, the average density of wind power is obtained as follows:

$$\overline{P} = \frac{1}{2} \overline{\rho} \times \int_0^\infty v^3 f(v,k,c) \times dv = \frac{1}{2} \times \overline{\rho} \times c^3 \times \Gamma\left(1 + \frac{3}{k}\right) \quad (24)$$

4. Results and Discussion

Mean monthly wind speeds at 10m of elevation at five sites were shown in Figure 2. The wind speed has a maximum value of 6.8 m/s at Daher El Baydar (in February), while the minimum wind speed of 3 m/s is recorded in September in Klaiaat.

The average annual minimum wind speed is obtained at Quaraoun and Les Cedres with a value of 3.9 m/s, while, the average annual maximum wind speed is recorded at Daher El Baydar with a value of 5.4 m/s. Table 3 shows the shape and scale parameters for the five sites, as estimated using the variability method, the standard deviation method, the Moroccan method, and the power density method. The curves that represent the measured cumulative frequencies and the estimated Weibull cumulative frequencies are given in Figure 3. For each site, there is not much difference between the parameters estimated by the four methods.

The parameters estimated by the Moroccan method and the variability method are very close, while the parameters estimated by the power density method are very close to the standard deviation method. For all sites, the curves given by the power density method were the closest to the measured distributions.

The results of the precision statistical indicators, RMSE and R^2 are given in Table 4 for the five sites and for the four methods used. The comparison of the four methods used with the measured values shows that the power density method gives the best estimate of the distribution measured for all sites except Quaraoun.

The RMSE values of the power density method for all sites are closest to zero and the R^2 values for this method are the closest to 1 for all sites

Table 3. Annual scale parameters for the five sites using the four methods

Methodology	Klaiaat		Marjyoun		Les Cedres		Quaraoun		Daher El Baydar	
	k	c (m/s)	k	c (m/s)	k	c (m/s)	k	c (m/s)	k	c (m/s)
Variability	1.7	4.77	1.77	5.23	1.58	4.11	1.65	4.4	1.95	6.25
Standard deviation	1.68	4.37	2.20	5.27	2.35	4.32	2.42	4.2	2.438	5.493
Power density	1.65	4.36	2.23	5.16	2.22	4.07	2.33	4.44	2.36	**6.30**
Moroccan	1.75	4.78	1.67	4.42	1.64	4.25	1.63	4.16	1.805	5.347

Table 4. Comparison of methods for the five studied sites

Sites	Statistical parameter	Variability method	Standard deviation method	Moroccan method	Power density method
Klaiaat	RMSE	0.0521	0.0389	0.0367	0.0367
	R^2	0.970	0.9836	0.9855	0.9855
Marjyoun	RMSE	0.0204	0.0263	0.0431	0.0225
	R^2	0.9966	0.9944	0.9849	0.9959
Les Cedres	RMSE	0.0590	0.0694	0.0643	0.0496
	R^2	0.9693	0.9574	0.9635	0.9782
Quaraoun	RMSE	0.0400	0.0254	0.0295	0.0386
	R^2	0.9559	0.9574	0.9923	0.9868
Daher El Baydar	RMSE	0.0332	0.0345	0.0359	0.0332
	R^2	0.9919	0.9912	0.9905	0.9919

except Quaraoun. The standard deviation method gives the best estimate for Quaraoun.

The monthly variation of the Weibull shape and scale parameters, which are estimated by the four methods used, is shown in Table 5 for the five sites studied. It can be observed that the form parameter k varies between 1.4 at Klaiaat (in March and April) and 3.04 at Les Cedres (in October). Therefore, the wind speed is more uniform at the Cedres during the month of October, whereas it is less uniform at Klaiaat during the months of March and April.

The scale parameter c varies between 3.44 m/s at Klaiaat (in September) and 7.66 m/s at Daher El Baydar (in February), which shows that Daher El Baydar is the most windy site. The maximum value of the average monthly power wind power density of 405.4 W/m^2 is

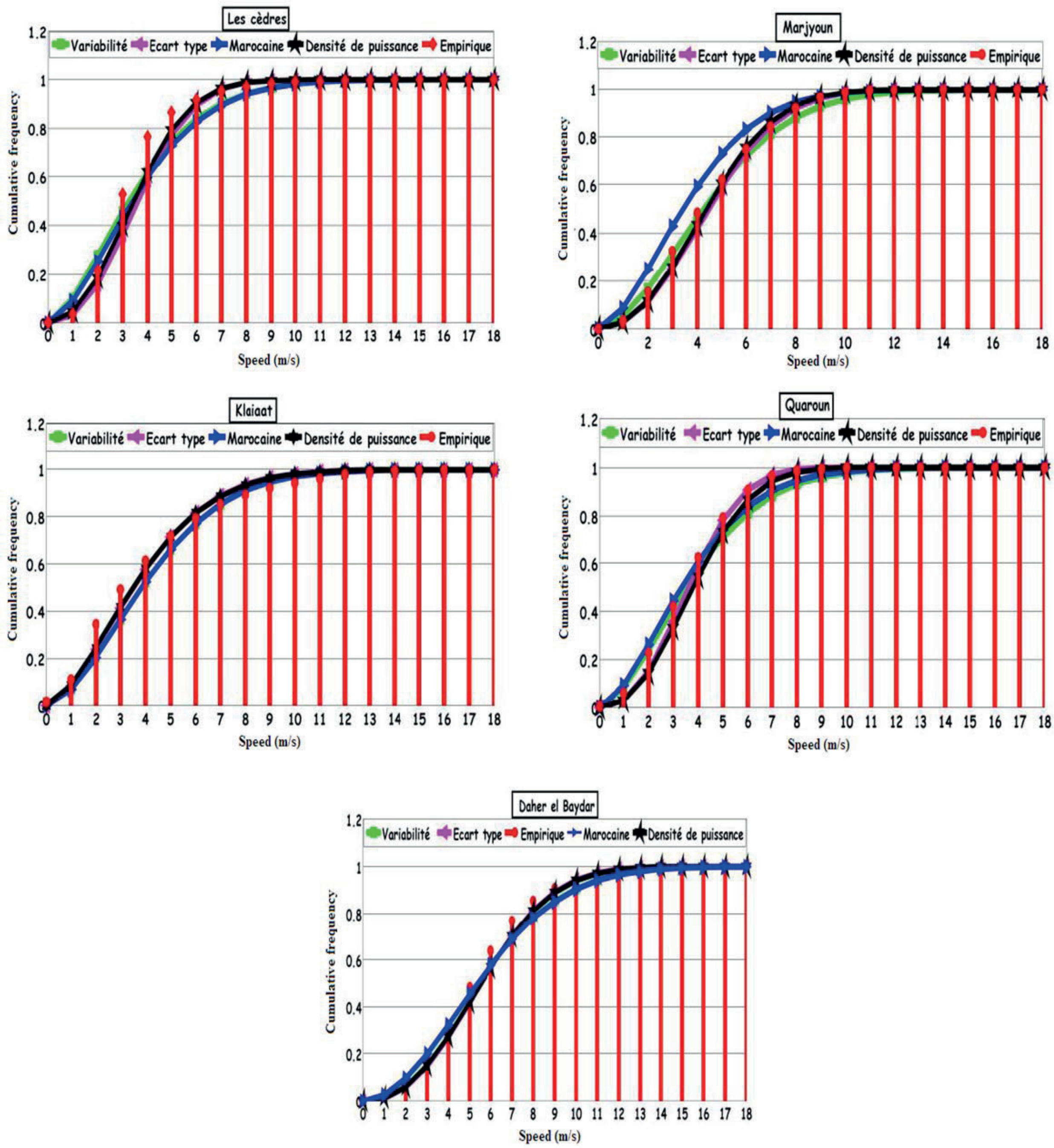

Figure 3. Comparison of the cumulative frequency calculated by the four methods for the five sites

Table 5. Estimation of form factor and monthly scale for the four methods

Standard deviation method										
Station	Les Cedres		Marjyoun		Quaraoun		Klaiaat		Daher El Baydar	
Month	k	c (m/s)	k	c (m/s)	k	c (m/s)	k	c (m/s)	k	c (m/s)
January	2.14	4.96	2.25	4.57	2.71	4.85	1.85	7.43	1.85	7.44
February	1.98	4.81	1.93	5.29	2.27	4.72	1.66	6.10	1.99	7.66
March	1.95	4.35	2.18	4.69	2.25	4.41	1.41	4.91	2.14	6.73
April	2.12	4.34	2.53	5.19	2.60	4.55	1.42	4.80	2.28	6.64
May	2.51	4.00	2.31	5.70	2.36	4.54	1.66	4.02	2.73	6.40
Jun	2.42	4.52	2.33	6.14	2.39	4.56	1.67	4.88	2.64	7.06
July	2.69	3.6	2.41	6.19	2.62	4.57	1.89	3.92	3.20	6.26
August	2.72	3.56	2.78	6.43	2.31	4.24	1.91	3.55	2.53	5.36
September	2.88	3.86	2.26	5.36	2.30	3.92	1.81	3.50	2.48	5.49
October	3.04	3.81	2.01	4.42	2.40	3.95	1.60	4.01	2.31	5.56
November	2.00	3.93	2.21	4.05	2.69	3.88	1.77	3.50	3.39	5.56
December	1.72	5.16	1.74	3.96	1.84	5.05	1.54	6.49	2.48	5.49

Moroccan method										
Station	Les Cedres		Marjyoun		Quaraoun		Klaiaat		Daher El Baydar	
Month	k	c (m/s)	k	c (m/s)	k	c (m/s)	k	c (m/s)	k	c (m/s)
January	1.75	4.94	1.70	4.54	1.74	4.82	2.05	7.45	2.05	7.46
February	1.73	4.79	1.80	5.27	1.72	4.69	1.92	6.15	2.07	7.66
March	1.66	4.32	1.71	4.66	1.67	4.37	1.77	5.02	1.97	6.72
April	1.66	4.3	1.78	5.17	1.69	4.53	1.75	4.90	1.96	6.63
May	1.60	3.96	1.85	5.69	1.69	4.51	1.61	4.01	1.94	6.42
Jun	1.69	4.49	1.90	6.13	1.70	4.54	1.75	4.9	1.01	7.08
July	1.53	3.55	1.91	6.19	1.69	4.55	1.59	3.88	1.93	6.32
August	1.52	3.52	1.94	6.45	1.64	4.21	1.52	3.49	1.81	5.35
September	1.58	3.84	1.80	5.33	1.59	3.87	1.51	3.45	1.82	5.48
October	1.57	3.79	1.67	4.38	1.59	3.90	1.61	4.01	1.83	5.54
November	1.59	3.88	1.61	4.00	1.58	3.85	1.51	3.45	1.74	4.83
December	1.78	5.16	1.60	3.99	1.77	5.03	1.95	6.59	1.83	5.54

Power density method										
Station	Les Cedres		Marjyoun		Quaraoun		Klaiaat		Daher El Baydar	
Month	k	c (m/s)	k	c (m/s)	k	c (m/s)	k	c (m/s)	k	c (m/s)
January	2.00	4.96	2.15	4.57	2.11	4.84	1.87	7.44	1.73	7.42
February	1.87	4.80	1.89	5.24	2.25	4.72	1.67	6.11	1.97	7.65
March	1.81	4.34	2.15	4.69	2.27	4.41	1.40	4.90	2.06	6.72
April	1.96	4.33	2.48	5.19	2.54	4.59	1.40	4.79	2.24	6.64
May	2.35	4.00	2.29	5.70	2.34	4.54	1.63	4.02	2.64	6.41
Jun	2.33	4.52	2.34	6.14	2.38	4.57	1.66	4.88	2.59	7.07
July	2.45	3.61	2.45	6.19	2.61	4.60	1.90	3.92	3.00	6.28
August	2.04	3.58	2.75	6.44	2.33	4.25	1.90	3.55	2.52	5.36
September	2.69	3.87	2.29	5.35	2.29	3.92	1.82	3.51	2.47	5.49
October	2.82	3.83	2.06	4.42	2.36	3.95	1.54	4.00	2.35	5.56
November	1.89	3.93	2.30	4.05	2.64	3.88	1.71	3.50	2.35	5.56
December	1.66	5.14	1.68	3.95	1.83	5.04	1.54	6.44	2.47	5.49

Variability method										
Station	Les Cedres		Marjyoun		Quaraoun		Klaiaat		Daher El Baydar	
Month	k	c (m/s)	k	c (m/s)	k	c (m/s)	k	c (m/s)	k	c (m/s)
January	1.74	4.94	1.67	4.53	1.78	4.82	2.13	7.45	2.13	7.46
February	1.71	4.79	1.80	5.27	1.70	4.67	1.94	6.15	2.16	7.66
March	1.63	4.31	1.69	4.66	1.64	4.36	1.75	5.02	2.02	6.72
April	1.63	4.29	1.78	5.17	1.67	4.53	1.73	4.90	2.01	6.64
May	1.56	3.95	1.86	5.69	1.66	4.50	1.57	4.01	1.98	6.43
Jun	1.66	4.48	1.94	6.14	1.67	4.53	1.73	4.89	2.07	7.09
July	1.48	3.54	1.94	6.19	1.67	4.55	1.55	3.87	1.96	6.33
August	1.48	3.91	1.99	6.46	1.61	4.20	1.47	3.48	1.81	5.35
September	1.54	3.83	1.88	5.54	1.55	3.86	1.46	3.44	1.83	5.48
October	1.53	3.78	1.64	4.38	1.55	3.90	1.57	4.00	1.84	5.54
November	1.55	3.87	1.57	4.99	1.54	3.84	1.46	3.44	1.75	4.82
December	1.78	5.16	1.56	3.93	1.75	5.03	2.00	6.59	1.84	5.52

Table 6. Estimated power density (W/m^2) for the five Lebanese sites selected

Station / Month	Les Cedres ρ=1.25kg/m^3	Marjyoun ρ=1.22kg/m^3	Quaraoun ρ=1.23kg/m^3	Klaiaat ρ=1.21kg/m^3	Daher El Baydar ρ=1.25kg/m^3	Total (W/m^2)
January	101,3790	72,1007	105,1542	357,3419	405,3525	1041,3283
February	99,1319	124,2847	101,9656	230,6532	378,0243	934,0596
March	76,3206	77,9308	87,6011	163,0609	244,6113	649,5247
April	68,9343	94,4613	95,5543	152,8625	218,6513	630,4637
May	46,0240	132,6015	94,5258	68,1959	175,3911	519,7383
Jun	66,8408	162,9873	95,5543	118,5913	238,0103	681,9839
July	32,8380	161,5761	96,8255	51,2862	154,7957	497,3215
August	37,3485	169,7514	80,6348	38,0914	105,4932	431,3194
September	38,1924	109,6441	66,7081	38,8066	114,8563	368,2075
October	36,1214	67,9337	68,8035	73,8545	123,6029	370,3161
November	37,9471	47,4013	40,7362	41,8713	123,6029	291,5606
December	143,1552	62,2786	122,2845	308,2157	114,8563	143,1552
Annual	784,2332	1282,9534	1056,3479	1642,8313	2397,2482	-

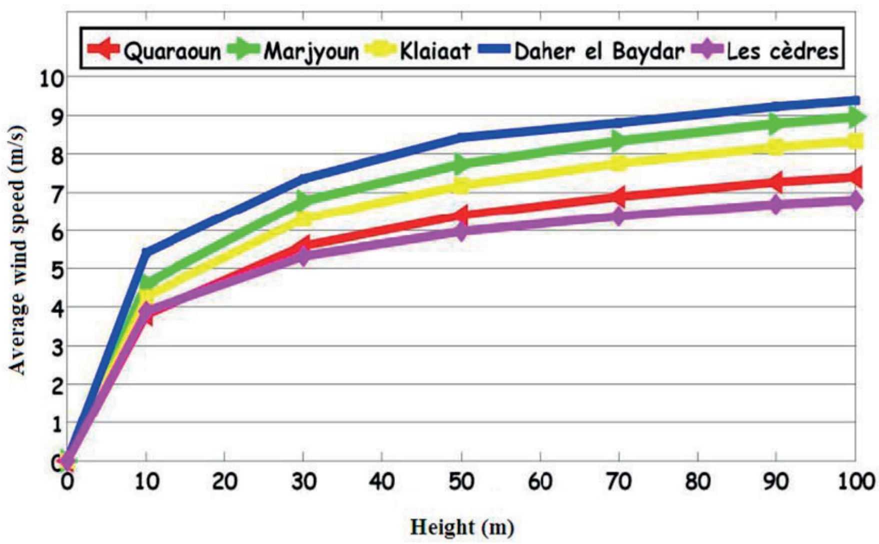

Figure 4. Average wind speed for different altitudes

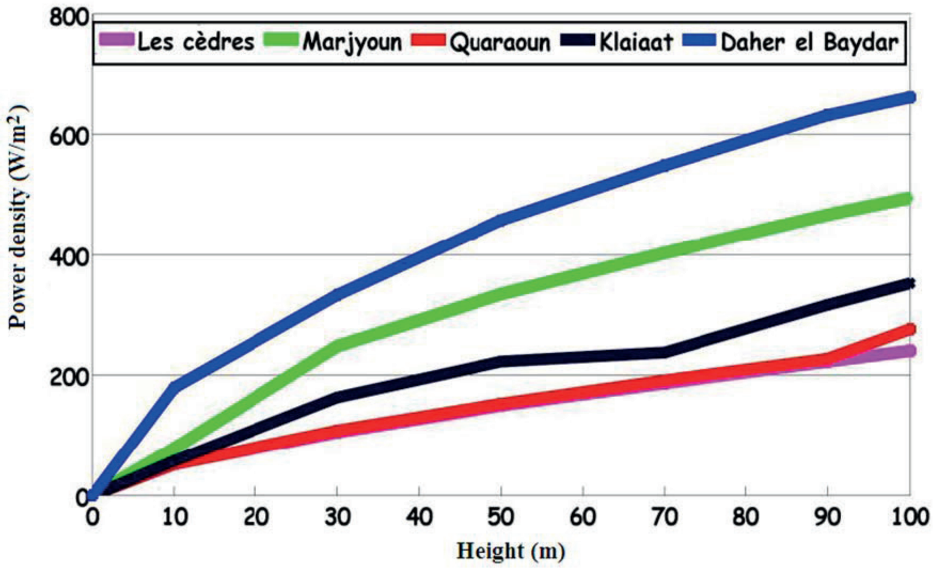

Figure 5. Evaluation of the power density for different altitudes

recorded at Daher El Baydar, in January, while the minimum value, 32.8 W/m^2, is recorded at the Cedres station, in July (Table 6).

The maximum annual average power density of 199.8 W/m^2 is recorded at Daher El Baydar, while the minimum value of 65.35 W/m^2 is recorded at Cedres (Table 6). The annual power density estimated at Klaiaat is 136.9 W/m^2 and that at Marjyoun is 109 W/m^2. Power density values at Klaiaat and Les Cedres are still significant, which means that wind turbine implantation at these two sites can be effective.

Figures 4 and 5 show the results obtained from the extrapolated wind characteristics. The wind speed and the power density increase with the altitude, we notice that at 50 m of altitude the average annual minimum wind speed of 6 m / s and the average annual minimum power density of 149 W/m^2, are recorded Les Cedres, while the annual average maximum velocity of 8 m / s and the average annual maximum power density of 456 W/m^2 are recorded at Daher El Baydar. At 100 m altitude, the average annual minimum wind speed of 6.9 m/s, and the annual average of minimum power density of 239.7 W/m^2, extrapolated are recorded at Les Cedres, while the extrapolated annual average of maximum velocity of 9.4 m/s and the annual average maximum power density of 661.23 W/m^2 are recorded at Daher El Baydar.

From 50m altitude, all sites have a wind speed higher than 6 m/s, which is good enough for the production of electricity with wind turbines.

Conclusions

From the available statistical data and the calculations made, we can draw the following conclusions:

- The power density method gives the best estimate of the distribution measured for all sites, with the exception of Quaraoun, the standard deviation method give the best estimate.
- The maximum average monthly wind speed value of 6.8 m/s is recorded at Daher El Baydar (in February) and the minimum value of 3.1 m/s is recorded at Klaiaat (in

September), while the minimum annual average wind speed of 3 .9 m/s is obtained Les Cedres, and the maximum value of 5.4 m/s is obtained at Daher El Baydar.

- The estimation of Weibull parameters (k and c) for all sites shows that the wind is sufficient during the first months of the year for a significant energy production.
- The power density estimate for all sites shows that the values of highest power densities are recorded during the first few months of the year. This is in agreement with the results obtained from the estimation of Weibull parameters.
- Daher El Baydar and Klaiaat are the best sites to harness the power of wind in Lebanon and produce significant electrical energy.

The results obtained make it possible to draw up excellent recommendations for wind turbine projects in Lebanon.

Acknowledgments

The first author thanks the ULB Xenophilia fund for its help in financing this doctoral project.

References

Akpinar, S., and Akpinar, E.K. 2007. Wind Energy Analysis Based on Maximum Entropy Principle (MEP)-Type Distribution Function. Energy Conversion and Management, 48(4): 1140 - 1149.

Bassil, G. 2010. National Strategic Plan for the Electricity Sector, Beirut-Lebanon. Ministry of Energy and Water, 39.

Ben Amar, F., Elamouri M., and Dhifaoui, R. 2008. Energy Assessment of the First Wind Farm Section of Sidi Daoud, Tunisia. Renewable Energy, 33(10): 2311-2321.

Darwish, A., and Sayigh, A. 1988. Wind Energy Potential in Iraq, Solar Technology and Wind, 5(3): 215-222.

De Herde, A., Gerin, P., Ledent, J. F., and Jeanmart, H. 2006. Wind Energy: What Hybrid Energy to Fulfill its Faults? Available at: http://www.apere.org/manager/docnum/ doc/doc1220_Eol_hybride_UCL-meca_061206.fiche%202.pdf.

Hamdan, S. 2011. 12%Renewable Energy in 2020: can we go further? Available at: http://mplbelgique.wordpress.com/2011/09/29/12-d%E2%80%99energy-environment-in-2020-can-be-on-longer.

Hassan, G. 2011. The National Wind Atlas of Lebanon. Beyrouth-Lebanon, UNDP, CEDRO: 64.

Justus, C.G., Hargraves, W.R., Mikhail, A., and Graber, D. 1978. Methods for estimating wind speed frequency distributions. Journal of applied meteorology, 17(3): 350-353.

Justus, C.G., and Mikhail, A. 1976. Height Variation of Wind Speed and Wind Distributions Statistics. Geophysical Research Letters, 3(5): 261-264.

Mabchour, H. 1999. Etude Modélisation et Expérimentation des Composants d'un Systeme Hybride Couplant les Energies Solaire et Eolienne: Performances et Méthodologie de Dimensionnement. Doctorat thesis: Energétique. Casablanca, Université Hassan II, Mohammedia.

Raichle, B.W., and Carson, W.R. 2009. Wind Resource Assessment of the Southern Appalachian Ridges in the Southeastern United States, Renewable and Sustainable Energy Reviews, 13(5): 1104 - 1110.

Ramirez, P., and Carta, J.A. 2005. Influence of the Data Sampling Interval in the Estimation of the Parameters of the Weibull Wind Speed Probability Density Distribution: A Case Study, Energy Conversion and Management, 46(15): 2419-2438.

Tannous, N., Habib, H.B., Harajli, H., Berberi, J., Seoud, J., and *et al.* 2010. Energy crisis. State of the environment and its trends in Lebanon.

Tar, K. 2008. Some Statistical Characteristics of Monthly Average Wind Speed at Various Heights. Renewable and Sustainable Energy Reviews, 12(6): 1712-1724.