International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 4 (2017) pp. 461-469

Analysis and Prediction of the Potential of Wind Energy in Tetouan, Northern Morocco using the Principle of Maximum Entropy

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Abstract

The identification and efficient estimation of the energy potential for a given site remains an indispensable step. For this purpose, several probability density functions (pdf) are used to model this potential, such as the classical Weibull function, the mixture functions such as the bimodal Weibull function, the function derived from the maximal entropy principle (MEP). In this paper, the wind energy potential is described by the probability function derived from the MEP; this function will be analyzed and compared with the results of the classical Weibull distribution. The wind speed measurements used are collected during the four seasons of the year 2014-2015 using a weather station of a wind farm located in the region of Tetouan. These data are selected as a sample to test the performance of the MEP. The comparison is based on the statistical test criteria, which are the coefficient of determination R^2, the coefficient Chi-square $\chi 2$, the coefficient defined by the square root of the mean square error RMSE, and the coefficient defined by the error Wind potential. The study shows that the density function derived from MEP describes better the wind speed measurements than the conventionally used Weibull density function and can represent the wind power density with much greater accuracy. Thus, the function derived from the MEP could be an alternative to the classical Weibull function when estimating the wind energy potential of a site, especially for sites where the shape of the frequency histograms of wind speeds is bimodal.

Keywords: Wind speed; probability density function; Maximum Entropy Principle; Weibull distribution; power density.

INTRODUCTION

The adjustment of the wind speed at a given site is usually described using the Weibull probability density function [1], in order to estimate the available wind potential and design of wind turbines with an adequate choice of wind turbines to be installed. In this context, several researchers have conducted studies to determine the two parameters of the Weibull distribution k and c (k shape parameter, c scale parameter) and then evaluate wind energy.

However, Weibull function can not represent all wind structures found in nature, particularly for sites whose calm wind is very important or with a bimodal distribution. In recent decades, several mixed probability functions have been proposed by researchers to model the wind potential of sites with complex wind distributions. Among these functions is the model based on the Maximum Entropy Principle (MEP), it has been shown that this model not only can describe the real data with more precision than the Weibull distribution but also for a wide range of data [2], [3], [4]. There are few studies devoted to the analytical determination of wind velocity distributions on the basis of (MEP) under constraints of mass conservation, momentum and flow energy [2]. To determine the distributions of the wind speed of the region of

After processing the data, we have calculated the mean of speed wind, the standard deviation, the frequent and energetic speeds, and wind potential. Then we conducted a comparative study of both MEP and Weibull adjustment methods.

MATHEMATICAL MODELS

A. *Weibull probability distribution function (W. PDF)*

The expression of the Weibull distribution has two parameters [1]:

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

With : $v>0$, k> 0 and c > 0

$v>0$: wind speed (m/s), c the scale parameter representing the value for which the function has a maximum in (m/s) and k is the dimensionless form factor.

The distribution function is given by:

$$F(v) = \int_0^{v_x} f(v)dv = 1 - exp\left(-\left(\frac{v_x}{c}\right)^{k}\right) \qquad (2)$$

Several methods have been used to adjust the Weibull distribution and to find the scale and shape parameters, but the maximum likelihood method and its derivative are the best efficient methods [5] [6]. Thus, we chose this method to determine the two Weibull parameters according to the following two formulas [5] :

$$C = \left(\frac{1}{N}\sum_{i=1}^{N} {v_i}^{k}\right)^{1/k} \quad (3)$$

And

$$k = \left(\frac{\sum_{i=1}^{N} {v_i}^{k} \ln v_i}{\sum_{i=1}^{N} {v_i}^{k}} - \frac{\sum_{i=1}^{N} \ln v_i}{N}\right)^{-1} \quad (4)$$

N represents the number of total non-zero observations and v_i is the ith saved mean wind speed.

The system of equations composed by equations (3) and (4) can be resolved by successive iterations using an optimization method such as the Newton Raphson.

In order to determine the wind factors that characterized the site, we identify the following parameters:

$\bar{v}$ denotes the mean wind speed, v_f the frequency wind speed, v_d is the energetic wind speed, P_d is the power density and σ is the standard deviation of the distribution of wind speed.

The tables1 and 2 summarize the expressions of the wind characteristics of the studied site for the arithmetic and Weibull distributions.

TABLE 1.THE EXPRESSIONS OF THE MEAN, FREQUENCY AND ENERGETIC SPEEDS OF THE WIND DEPENDING THE MODEL.

Distribution	**Mean wind speed V_m**	**frequency wind speed v_f**	**energetic wind speed V_e**
Arithmetic	$\sum_{i=1}^{n} v_i f_i$	$v[f(v)_{max}]$	$v[P_d(v)_{max}]$
Weibull	$C\Gamma\left(1+\frac{1}{k}\right)$	$C\left(1+\frac{1}{k}\right)^{1/k}$	$C\left(1+\frac{2}{k}\right)^{1/k}$

Where Γ , the standard gamma function is given by:

$$\Gamma(x) = \int_0^{\infty} t^{x-1} e^{(-t)} dt \quad (5)$$

TABLE 2. EXPRESSIONS OF THE POWERS DENSITY AND STANDARD DEVIATION DEPENDING THE MODEL.

Distribution	**Power density P_d**	**Standard Deviation σ**
Arithmetic	$\frac{1}{2}\frac{16}{27}\rho \sum_{i=1}^{n} {v_i}^3 f_{(v_i)}$	$\left[\sum_{i=1}^{n}(v_i - v_m)^2 f(v_i)\right]^{\frac{1}{2}}$
Weibull	$\frac{1}{2}\frac{16}{27}\rho C^3 \Gamma\left(1+\frac{3}{k}\right)$	$C\left[\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right]^{1/2}$

ρ: air density (kg/m^3) at the site; is often written in a simple form [1]:

$$\rho = \rho 0 - (1.194 \times 10^{-4}\, H_m) \quad (6)$$

Where, H_m is the site elevation in meters and ρ_0 is the air density value at sea level (ρ_0 = 1.225).

B. *Maximum Entropy Principle (MEP)*

If we consider a random process x producing realizations {x1, x2, ..., xn} and assign the probabilities {pl, p2, ..., pn} to these realizations to represent the partial information on this process.

Shannon [7] defined the entropy of this process by the weighted sum of the individual information of each realization with the following relation:

$$H(P) = \sum_i p_i \ln\left(\frac{1}{p_i}\right) = -k\sum_i p_i \ln(p_i) \quad (7)$$

With, pi is the probability of state i and k is the Boltzmann constant.

In 1957, Jaynes [2], [4], [8] introduced the Maximum Entropy Principle (MEP) under constraints for assigning a probability distribution for a random variable.

The problem is mathematically formulated as follows:

$$Max\_H(P) = -k\sum_i P_i \ln(P_i) \quad (8)$$

Under the following constraints:

- The additional constraint to obtain a distribution of normalized probability:

$$\sum_{i=1}^{N} P_i = 1 \quad (9)$$

- Physics constraints for the system under study [9] :

$$\sum_{i=1}^{N} P_i g_{r,i} = \langle g_r \rangle, r = 1, 2, 3, \ldots, m \quad (10)$$

Where m is the number of physics constraints for the system studied, $g_{r,i}$ is a function evaluated at the state i and $\langle g_r \rangle$ is the expectation of average value of the function $g_{r,i}$ on the entire system.

To find the maximum value of equation (6) under the constraints of equations (3) and (4), we used the Lagrange method:

The corresponding Lagrangian is given by:

$$L = -k\sum_{i=1}^{N} P_i \; ln(P_i) - \alpha_0\left(\sum_{i=1}^{N} P_i - 1\right) - \sum_{i=1}^{N}\alpha_r\left[\sum_{r=1}^{m} P_i g_{r,i} - \langle g_r\rangle\right] \qquad (11)$$

Where α_0 and α_r are the Lagrange multipliers respectively associated with the two constraints of equations (7) and (8).

Therefore, for L to be extremal it is necessary that:

$$\forall i, \qquad \frac{\partial L}{\partial P_i} = 0 \qquad (12)$$

Thus, we get:

$$P_i = \exp\left(-\alpha_0 - \alpha_1 g_{1,i} - \ldots - \alpha_m g_{m,i}\right) \qquad (13)$$

The multiplier α_0 can be determined by substituting equation (11) into equation (7) [8], [9]:

$$\alpha_0 = \ln\left(\sum_{i=1}^{n}\exp\left(-\sum_{r=1}^{m}\alpha_r g_{r,i}\right)\right) \qquad (14)$$

In the context of wind energy, this MEP can be applied to determine the distribution of the wind speed. The constraints are mainly formulated from the following conservation laws [2] :

- Mass conservation of the air :

$$\dot{m} = \sum_i \rho P_i V_i S = \rho S V_{10} \qquad (15)$$

- Momentum conservation of the air :

$$\dot{M} = \sum_i (\rho P_i V_i S).V_i = \rho S V_{20}^2 \qquad (16)$$

- Energy conservation of the air :

$$\dot{E} = \sum_i (\rho P_i V_i S).\left(\frac{1}{2}V_i^2\right) = \frac{1}{2}\rho S V_{30}^3 \qquad (17)$$

- Calm wind probability occurrence conservation :

$$P_0 = exp(-\alpha_0) \qquad (18)$$

Where ρ is the air density, V_i the wind speed and S the area swept by the blades of the turbine.

V_{10} is the mean wind speed; V_{20} and V_{30} indicate the equivalent mean wind speeds, traversing the rotor and producing respectively same force and same energy. P_0 is the probability occurrence of the calm wind speed.

If we consider the air density ρ and swept by the rotor blades S are constants, the constraints equations (13) - (15) become:

$$\sum_i P_i V_i = V_{10} \qquad (19)$$

$$\sum_i P_i V_i^2 = V_{20}^2 \qquad (20)$$

$$\sum_i P_i V_i^3 = V_{30}^3 \qquad (21)$$

These equations are used to calculate the speeds V_{10}, V_{20} and V_{30} using wind data. Thus, the most probable distribution which maximizes the entropy function under the constraints of equations (17)-(19) and the probability normalization (7) is an exponential function, similar to equation (11), of the form :

$$f(V_i) = P_i = \exp(-\alpha_0 - \alpha_1 V_i - \alpha_2 V_i^2 - \alpha_3 V_i^3 - \alpha_4 V_i^4) \qquad (22)$$

Where α_r ($0 \le r \le 4$) are the Lagrange multipliers and V_i indicates the speed of the wind classified.

The multiplier α_0 is determined from the measured frequency $f(V_i = 0\,m/s)$ of the calm wind with equation:

$$\alpha_0 = -\ln[f(0)] \qquad (23)$$

The other Lagrange's multipliers $\alpha_1, \alpha_2, \alpha_3$ and α_4 satisfy the condition of the distribution normalization (7) and the conservation laws (17) - (19) are determined by the equations system:

$$\begin{cases} \sum_i exp[g(V_i)] - 1 = 0 \\ \sum_i V_i.exp[g(V_i)] - V_{10} = 0 \\ \sum_i V_i^2.exp[g(V_i)] - V_{20}^2 = 0 \\ \sum_i V_i^3.exp[g(V_i)] - V_{30}^3 = 0 \end{cases} \qquad (24)$$

With

$$g(V_i) = -\alpha_0 - \alpha_1 V_i - \alpha_2 V_i^2 - \alpha_3 V_i^3 - \alpha_4 V_i^4$$

After the determination the value of α_0 multiplier equation (19) and the mean speeds V_{10}, V_{20} and V_{30} with equations (17), (18), (19); we can use Newton-Raphson method to solve the equation system (22).

By knowing the Lagrange multipliers α_r (0≤r≤4), the distribution of wind speed frequency is determined by (20).

Les tables 3 et 4 exposent les expressions des caractéristiques éoliennes du site étudié pour le PME.

TABLE 3. THE EXPRESSIONS OF THE MEAN, FREQUENCY AND ENERGETIC SPEEDS OF THE WIND FOR THE MODEL OF MEP.

Distribution	Mean wind speed V_m	frequency wind speed v_f	energetic wind speed V_e
MEP	$\int_0^{\infty} Vf(V)dV$	$V[f(V)_{max}]$	$V[P_d(V)_{max}]$

TABLE 4. EXPRESSIONS OF THE POWERS DENSITY AND STANDARD DEVIATION FOR THE MODEL OF MEP.

Distribution	Power density P_d	Standard Deviation σ
MEP	$\frac{1}{2}\frac{16}{27}\rho\int_0^{\infty} V^3 f(V)$ (	$\left[\int_0^{\infty}(V-V_m)^2 f(V)dV\right]^{\frac{1}{2}}$

DATA MEASURES

The data measures wind speed used to cover a period of the year 2014-2015, they were collected from a weather station of wind farm of Tetouan at 10m, which is located in Saddina (region of Tangier-Tetouan-Al Hoceima in northern Morocco) .

The region of Tangier-Tetouan-AlHoceima is one of the twelve regions of Morocco. It covers an area of 15,090 km². The capital of the region is Tangier. It is the northernmost of Morocco's twelve regions. In the north, it faces the Strait of Gibraltar and the Mediterranean Sea and borders Ceuta. It also borders the Moroccan regions of Rabat-Salé-Kénitra to the southwest, Fès-Meknès to the southeast and Oriental to the east.

The climate of the region is Mediterranean on the coast and the surrounding area, rather continental and with heavy snow over inland areas of the region. Thanks to its altitude and triple coastline, the region is one of the rainfall zones in Morocco, and it is one of the windiest regions of the world with steady winds.

Table 5 shows the data of the frequency distribution of wind speeds and mean speeds according to the speed classes for the year and the four seasons, which are used to evaluate the W. PDF and MEP models.

TABLE 5. FREQUENCY DISTRIBUTION OF WIND SPEEDS

Classes of wind speeds	Frequency (%)				
	Annual	*Winter*	*Spring*	*Summer*	*Autumn*
0-1	3,38	3,65	3,46	2,85	3,56
1-2	3,81	4,17	4,69	3,80	3,23
2-3	6,76	6,34	7,65	6,43	6,74
3-4	9,34	8,81	8,51	11,22	8,52
4-5	10,89	8,71	10,61	13,49	9,50
5-6	11,33	8,76	11,26	13,56	10,86
6-7	10,73	8,90	11,26	11,55	12,31
7-8	10,36	7,81	9,88	12,06	9,93
8-9	7,72	6,82	7,07	7,49	9,27
9-10	5,90	6,39	5,41	5,26	6,32
10-11	4,66	6,11	4,33	3,76	5,01
11-12	4,69	7,39	3,54	2,63	5,66
12-13	3,38	5,02	2,89	2,01	3,51
13-14	2,20	3,17	2,16	1,32	2,43
14-15	1,95	2,94	2,16	1,39	1,59
15-16	1,40	1,99	2,38	0,80	1,08
16-17	0,79	1,47	1,23	0,29	0,28
17-18	0,35	0,57	0,94	0,07	0,05
18-19	0,29	0,80	0,36	0,00	0,05
19-20	0,06	0,09	0,22	0,00	0,05
20-21	0,02	0,09	0,00	0,00	0,00
21-22	0,01	0,00	0,00	0,00	0,05
22-23	0,00	0,00	0,00	0,00	0,00
23-24	0,00	0,00	0,00	0,00	0,00
24-25	0,00	0,00	0,00	0,00	0,00
V_m (m/s)	**6,88**	**7,58**	**6,93**	**6,28**	**6,92**

STATISTICAL STUDY

To evaluate the performance of the two models (MEP and Weibull), we used three statistical tests: the root mean square error RMSE, the determination coefficient R^2 the Chi - square χ2 and the relative error in relation with the wind power density that are defined in the following relation [10]:

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2\right]^{\frac{1}{2}} \quad (25)$$

$$\chi^2 = \frac{\sum_{1=1}^{N}(y_i - x_i)^2}{N - n} \qquad (26)$$

$$R^2 = \frac{\sum_{1=1}^{N}(y_i - z_i)^2 - \sum_{1=1}^{N}(y_i - x_i)^2}{\sum_{1=1}^{N}(y_i - z_i)^2} \qquad (27)$$

Where y_i is the ith value of the probability of real data, z_i is the mean value of real data, x_i is the ith estimated with both models, N is the number of observations and n is the number of constants used.

$$Err\ (\%) = 100.\left|\frac{P_{d_{Weibull\ PME}} - P_{d_{Statistique}}}{P_{d_{Statistique}}}\right| \qquad (28)$$

The best results are characterized by a high value of R^2 test, and low values for RMSE and χ^2 tests.

RESULTS AND DISCUSSION

To study the reliability of the two probability density functions presented, different comparisons were made from the measured wind speed data. Thus, Figures 1, 2, 3, 4 and 5 show the seasonal and annual frequency distributions of the speed; And Figures 6, 7, 8, 9 and 10 show the seasonal and annual wind energy distributions of the site studied for the year 2014-2015 at 10 m for the Tetouan region.

The results of the different analyzes carried out on the two models studied are presented in tables. So, table 6 lists the calculated values of the Lagrange multipliers and the shape (k) and scale (c) parameters of the Weibull distribution, table 7 summarizes the annual and seasonal wind characteristics of the wind farm, table 8 presents the density, error and energy of the site studied for the two models, and finally the various statistical parameters are summarized in table 9.

Figure 1. The MEP and Weibull distributions of the wind speed frequency of the site for the year 2014-2015.

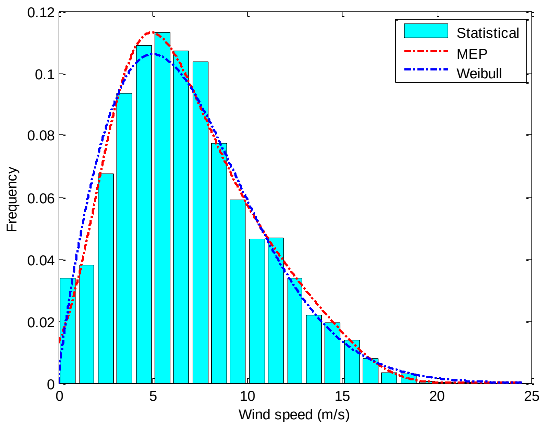


Figure 2. The MEP and Weibull distributions of the wind speed frequency of the site for the winter season 2014-2015.

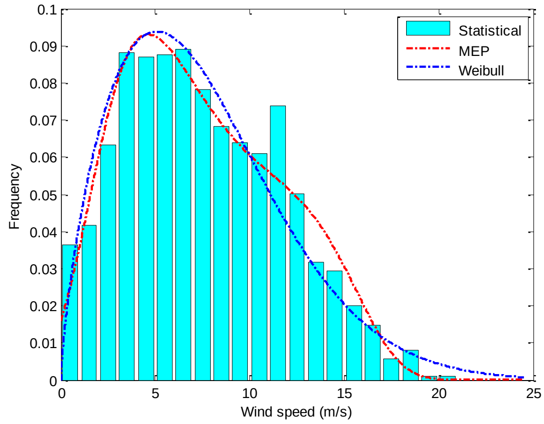


Figure 3.The MEP and Weibull distributions of the wind speed frequency of the site for the spring season 2014-2015.

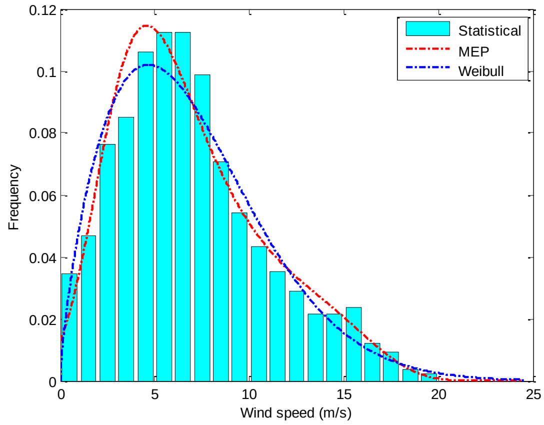


Figure 4. The MEP and Weibull distributions of the wind speed frequency of the site for the summer season 2014-2015.

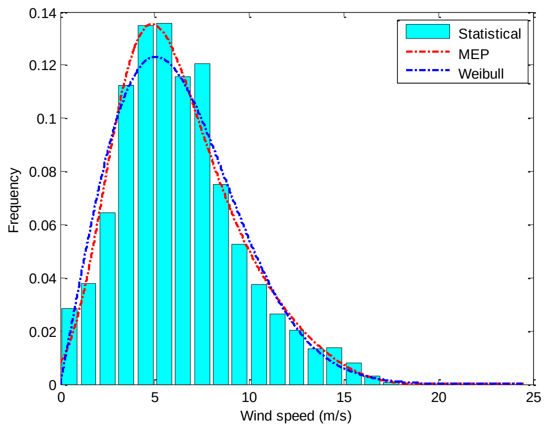


Figure 5. The MEP and Weibull distributions of the wind speed frequency of the site for the autumn season 2014-2015.

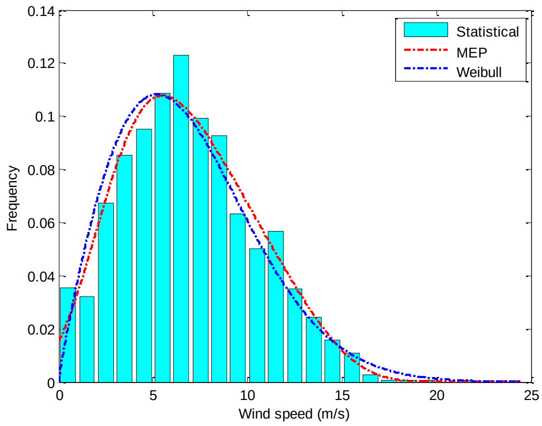


Figure 6. The MEP and Weibull distributions of the energy of the site for the year 2014-2015.

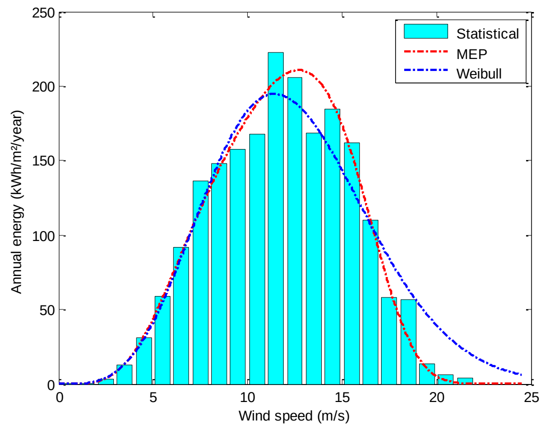


Figure 7. The MEP and Weibull distributions of the energy of the site for the winter season 2014-2015.

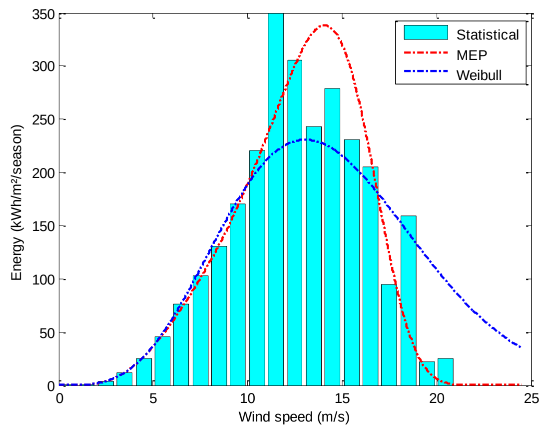


Figure 8. The MEP and Weibull distributions of the energy of the site for the spring season 2014-2015.

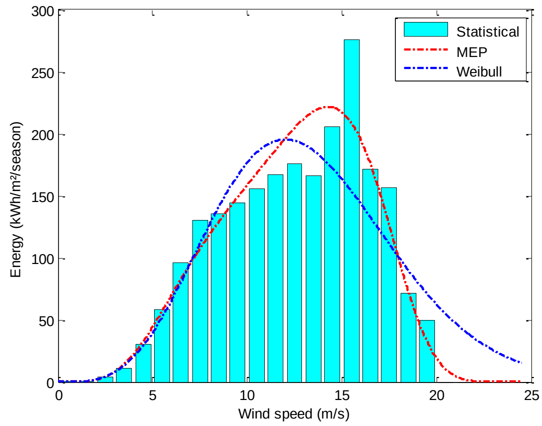


Figure 9. The MEP and Weibull distributions of the energy of the site for the summer season 2014-2015.

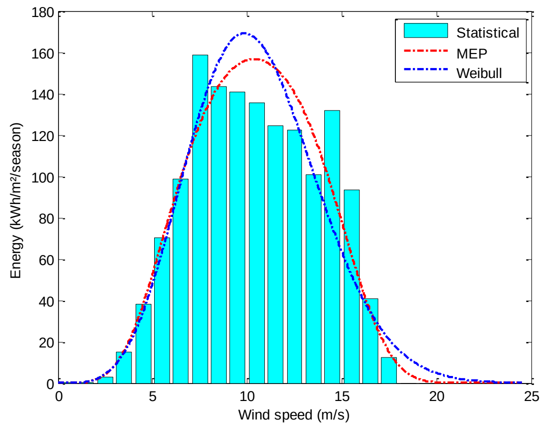
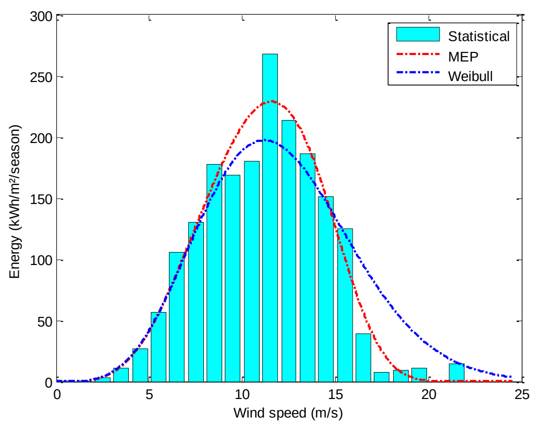


Figure 10. The MEP and Weibull distributions of the energy of the site for the autumn season 2014-2015.



The analysis of figures 1, 2, 3, 4 and 5 shows:

- The histograms of the classes of the seasonal and annual frequency distributions of the wind speed of the site studied for the year 2014-2015 are in unimodal form except for the winter season that is bimodal.

- The PME method takes into account the calm wind (v = 0 m/s) while the Weibull distribution ignores it.

- The model derived from PME shows a better fit for wind speed and better matches the class histogram for the annual measure and the three seasons (spring summer and autumn) (figures 1, 3, 4 and 5) whose form is modal.

- The model derived from the PME adjusts the frequency distributions of the winter season (bimodal) better than the Weibull distribution (figure 2).

The analysis of figures 6, 7, 8, 9 and 10 shows that the MEP method adjusts the energy distribution of the studied site better than the Weibull method for the year 2014-2015 and for these four seasons.

An analysis of Tables 7, and 8, shows that the values of the mean speed, the power density and energy available calculated by the method developed MEP coincide exactly with that calculated by the statistical method; indeed, the calculated relative error is almost zero. However, the difference values frequent and energetic speed is remarkable. The annual mean wind speed in the region of Tetouan at 10m is very important. It is equal to 6.88 m/s at 10m. While the seasonal mean speeds vary between a minimum of 6.28 m/s at 10m (in summer) and a maximum value of 6.62 m/s to 10m (in winter); thus fluctuation in wind speed is not negligible throughout the year in the region of Tetouan. Indeed, the value of the standard deviation σ for the year (2014/2015) is equal to 3.67, it is more than half the mean speed (6.88 m/s). Then we can consider that variations in wind speed are significant around the mean.

Concerning the seasonal and annual power densities calculated from the statistical method and those obtained from the two models Weibull and MEP, we see that the power density varies from season to season. Indeed, it is minimal in summer with 186,07 W/m² and maximum in winter with 415,33W/m² (Table 8).

The statistical analysis shows an agreement with the results observed graphically; in effect the greatest values for the coefficient of determination R^2 (≈1) and low values for the other two coefficients χ^2 -Chi square- and RMSE -root mean square error- (Table 9-10) confirm that MEP method is much better than the Weibull distribution to describe the set of wind speed data

TABLE 6. THE ANNUAL AND SEASONAL VALUES OF LAGRANGE MULTIPLIERS AND WEIBULL PARAMETERS FOR REGION OF TETOUAN FOR THE YEAR (2014-2015) .

Height =10m	Weibull parameters		Lagrange multipliers				
	c (m/s)	*k*	α_0	α_1	α_2	α_3	α_4
Annual	7,68	1,84	4,36506036	-1,1171085	0,1914476	-0,01269269	0,0003211
Winter	8,40	1,73	4,13394414	-0,98304013	0,1869994	-0,01402687	0,0003826
Spring	7,73	1,73	4,34735218	-1,18248753	0,211934	-0,01418811	0,000345
Summer	7,06	2,04	4,81983755	-1,45138488	0,2491014	-0,01640506	0,0004182
Autumn	7,70	1,91	4,17462153	-0,90725086	0,1456305	-0,00968457	0,000272

TABLE 7. ANNUAL AND SEASONAL CHARACTERISTICS OF WIND IN THE REGION OF TETOUAN FOR THE YEAR (2014-2015) .

Height=10m	V_m (m/s)			V_e (m/s)			V_f (m/s)			σ (m/s)		
	Statistical	*MEP*	*Weibull*	*Statistical*	*MEP*	*Weibull*	*Statistical*	*MEP*	*Weibull*	*Statistical*	*MEP*	*Weibull*
Annual	6,88	6,88	6,83	12	12,72	8,73	6	4,94	6,45	3,72	3,67	3,85
Winter	7,58	7,58	7,49	12	14,09	10,50	7	4,65	7,68	4,21	4,14	4,47
Spring	6,93	6,93	6,89	16	14,29	12,07	6	4,59	10,07	3,98	3,93	4,11
Summer	6,28	6,28	6,26	8	10,40	6,88	6	4,86	5,17	3,18	3,14	3,22
Autumn	6,92	6,91	6,83	12	11,58	8,27	7	5,55	6,15	3,53	3,46	3,73

TABLE 8. DENSITY, ERRORS AND ENERGY STUDY SITE IN TETOUAN REGION FOR THE YEAR (2014-2015).

Height=10m	P (W/m²)			Error (%)		E (kWh/m² /year or /season)		
	Statistical	*MEP*	*Weibull*	*MEP*	*Weibull*	*Statistical*	*MEP*	*Weibull*
Annual	282,51	282,51	240,64	0,00196	16,89	2474,81	2056,80	2474,76
Winter	415,33	415,33	362,37	0,00062	22,08	3638,33	2834,95	3638,30
Spring	302,69	302,69	256,16	0,00053	14,97	2651,57	2254,63	2651,55
Summer	186,07	186,07	156,25	0,00084	12,08	1630,02	1433,08	1630,00
Autumn	262,47	262,47	228,13	0,00020	13,69	2299,24	1984,41	2299,23

TABLE 9. STATISTICAL ANALYSIS PRAMETERS FOR THE ANNUAL AND SEASONAL WIND SPEED DISTRIBUTION IN TETOUAN REGION FOR THE YEAR (2014-2015).

Height =10m	Weibull distribution			MEP distribution		
	R^2	$\chi 2$	*RMSE*	R^2	$\chi 2$	*RMSE*
Annual	0,99999941	9,645E-08	0,00031053	0,99999943	1,3309E-08	0,00028258
Winter	0,99999896	7,8526E-07	0,00088573	0,99999934	4,4656E-07	0,00066746
Spring	0,99999853	1,2168E-06	0,00110227	0,99999884	9,9915E-07	0,00099777
Summer	0,9999978	6,2411E-07	0,00078971	0,99999869	4,6682E-07	0,00068262
Autumn	0,9999989	7,1661E-07	0,00084613	0,99999908	5,1006E-07	0,00071335

CONCLUSION

In this article, we used the method based on the maximum entropy principle to estimate the wind energy potential of the region of Tetouan. The results were compared with those calculated using the conventional method of Weibull. We used the coefficient of determination R^2, Chi-square $\chi 2$, root mean square error RMSE and the relative error of wind potential as statistical tests.

Analysis of the different results obtained shows that:

- The MEP distribution adjust better the measured wind speed than the classical Weibull distribution and it is best suited for all types of data measured wind speed (unimodal, bimodal).
- The distribution MEP describes the wind power density accurately than the Weibull distribution. Consequently, the MEP distribution is more appropriate for assessing the energy potential.

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