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Assessment of wind resources in Braşov region (Romania)

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Abstract
The accurate assessment of wind potential for an area requires both the knowledge of probability density function and the power density of wind. For this purpose, for the area of interest are required databases that to contain direct measurements of wind parameters recorded during at least one year. In order to model the wind speed, Weibull distribution is used. However, the use of Weibull distribution is most often difficult due to the need of knowing the Weibull distribution parameters (the shape parameter and the scale parameter). Considering this aspect, this paper proposes a method for estimating the Weibull parameters using their dependence on the Gamma function. The exemplification is made through a case study, by processing of data recorded by two weather stations located in two different areas of Braşov. The proposed algorithm is a method easily to apply to any location that has a secure database.

Keywords: Maximum energetic wind speed; Mean wind speeds; Power density; Weibull parameters; Weibull probability density function.

1. Introduction

At present, the use of wind energy is widespread due to some benefits such as the significant reducing of toxic gases produced to power generation by burning fossil fuels; diversification of sources for energy production and the development of new technologies to capitalize renewable energy; the capitalization of renewable resources energy of isolate areas for their introduction into the economic circuit.
Nowadays, the use of wind energy refers primarily to non-polluting electricity produced at a significant scale with wind turbines.
The full knowledge of the conversion technology of wind energy into electricity involves knowledge in different areas: aerodynamics, electrical engineering, mechanical engineering, civil engineering, etc., but also in the field of meteorology. It is envisaged that the formulation of a correct decision regarding the investments opportunity for implementation of wind energy conversion systems requires information on wind energy resources of the site where it will be built a possible wind power plant.
At present though the technical literature proposes wind maps, this does not publish the evaluation methods used for their development [1-3].
Regarding the expressions of shape parameter we mention, commonly technical literature [4, 5] offers a power expression of this depending on the turbulence intensity.
In addition, although there are a number of specialized software (for instance WAsP, UPMORO, UPMPARK, Wind Power, WindPro programs) for calculating wind climatology statistics (maps, graphs,

images characteristic to common wind atlases but also numerical information in tabular form regarding to the wind speed and power density, estimations on wind energy potential) the estimation models used are not known [6, 7].
It should also be noted that the results provided – even complex – can be applied only to the station site where the measurements were carried out. It is envisaged that wind speed can vary both in time, depending on weather conditions and also over short distances; therefore the assessment procedures of wind turbines location must consider all regional parameters that are likely to influence the wind conditions, namely: obstacles in close proximity, description of land roughness, orography (such as hills, these could cause acceleration or deceleration effects of air flow), climate, environmentally protected areas.
Considering this aspect, the paper proposes a method to estimate the Weibull parameters (and finally the wind power density) and that to be easily to apply if a decision on the opportunity of placement of wind turbines in certain geographical areas must be taken.

2. Material and methods

2.1 Weibull probability distribution function

The widely used distribution for statistical modelling of wind speed variation for a given site is represented by the Weibull probability distribution with two parameters.
The probability density function of wind speed is given by Weibull distribution, as follows [7-9]

$$f(v) = k / A(v / A)^{k-1} \, exp\left(-(v / A)^{k}\right) \tag{1}$$

where A and k represent the parameters of Weibull probability distribution, A – the scale parameter (m/s) and k – the shape parameter.
Equation (1) can be written depending on Gamma function [10]:

$$f(v) = k / \bar{v}\,\Gamma(1+1/k)\left(v / \bar{v}\,\Gamma(1+1/k)\right)^{k-1} exp\left(-\left(v / \bar{v}\,\Gamma(1+1/k)\right)^{k}\right) \tag{2}$$

where $\Gamma(1+1/k)$ represents the Gamma function for argument $(1+1/k)$.
The scale parameter is calculated as below

$$A = \bar{v} / \Gamma(1+1/k) \tag{3}$$

where $\bar{v}$ represents the mean of wind speed observations and it is defined as:

$$\bar{v} = 1/n\sum_{i=1}^{n} v_i \tag{4}$$

where n is the number of wind speed observations, v_i – the i^{th} wind speed data value.
The cumulative distribution function represents the integral of Weibull probability density function and is calculated with the following equation [10]:

$$F(v) = 1 - exp\left(-\left(v / \bar{v}\,\Gamma(1+1/k)\right)^{k}\right) \tag{5}$$

This function is often used to compute probabilities.
One of the phenomena that negatively influence the turbine rotor is turbulence; this leads to increase mechanical stress caused by short gusts of wind, the propeller material wearies and could destroy.
The indicator that characterizes the wind turbulence is the turbulence intensity defined as the ratio of standard deviation and average speed over a specified period of time, respectively

$$\sigma / \bar{v} = \sqrt{\Gamma(1+2/k) / \Gamma^{2}(1+1/k) - 1} \tag{6}$$

The wind turbulence refers to fluctuations in wind speed on a short period of time. The turbulence is caused by two phenomena: the friction between the airflow and the surface of the earth (often enhanced by topographical features of the relief, namely the presence of valleys, hills and mountains); the second phenomenon relates to thermal effects which cause the vertical movements of air masses [7].
Concomitant with increasing height, wind turbulence decreases.
It must be mentioned that the most frequent wind speed, v_{mp}, and the maximum energetic wind speed, v_{maxE}, can be also described using Weibull distribution parameters [8, 9, 11-13]:

$$v_{mp} = A(1-1/k)^{1/k} \tag{7}$$

$$v_{max\,E} = A(1+2/k)^{2/k} \tag{8}$$

2.2 Wind power density and wind energy
The mean wind power represents the product of mass flow rate that crosses the wind turbine blades, ρvS, and the kinetic energy of wind per unit mass, $v^2/2$ [7]:

$$\overline{P(v)} = 0.5\,\rho\,S\,\bar{v}^3 \tag{9}$$

where $\rho = 1.225$ kg/m^3 represents the air density considering normal air pressure and the air temperature of 15^{o}C), $P(v)$ (W) – the wind power and S (m^2) – the swept area of rotor blades.
The wind power density (wind power per unit area) of the selected site, $p(v)$ (W/m^2), can be expressed depending on Weibull parameters as [4, 5, 7]:

$$p(v) = P(v)/S = 0.5\,\rho\,A^3\Gamma(1+3/k) \tag{10}$$

3. Calculations
3.1 Relations for Gamma function and the shape parameter of Weibull distribution
The determination of probability density function, the wind turbulence (the ratio between the standard deviation and average wind speed), the value of the most frequent wind speed, the value of the maximum energetic wind speed and even the wind power density can be achieved using the Gamma function. For situations where it is desired the development of own procedures for estimating the parameters mentioned above and the software used for this purpose do not have functions for statistical analysis, this paper proposes the estimation of Gamma function using equation (11) or equation (12) depending on the argument value:

$$\Gamma(x) = 0.7282\,x^4 - 4.1991\,x^3 + 9.3776\,x^2 - 9.6245\,x + 4.7116 \tag{11}$$

$$\Gamma(x) = 0.0416\,x^6 - 0.67\,x^5 + 4.6327\,x^4 - 17.192\,x^3 + 36.15\,x^2 - 40.544x + 19.673 \tag{12}$$

As it was seen in previous chapters, a complete analysis of wind statistic requires the knowledge of shape parameter. It is obvious the fact that the use of a more accurate expression of shape parameter leads to more precise estimations of Weibull probability density function, Weibull cumulative distribution function, wind power density and maximum energetic wind speed.
This paper proposes the determination of shape parameter using equation (6). Knowing the values of Gamma function, the right term of equation (6) can be graphically represented for different values of shape parameter (Figure 1); thus, the expressions of shape parameter, k, that best approximates the curve plotted on the graph, can be determined.
We propose for the shape parameter, k, the use of equation (13),

$$k = 1.0275(\sigma/\bar{v})^{-1.073} \tag{13}$$

Or for a more accurate determination, depending on the intensity turbulence value, the use of one of the equations (14), (15) or (16)

$$k = 1.0618(\sigma/\bar{v})^{-1.056} \quad for \ \sigma/\bar{v} \le 0.2 \tag{14}$$

$$k = 0.9736(\sigma/\bar{v})^{-1.111} \quad for \ 0.2 < \sigma/\bar{v} \le 0.8 \tag{15}$$

$$k = 1.013(\sigma/\bar{v})^{-0.922} \quad for \ 0.8 < \sigma/\bar{v} \tag{16}$$

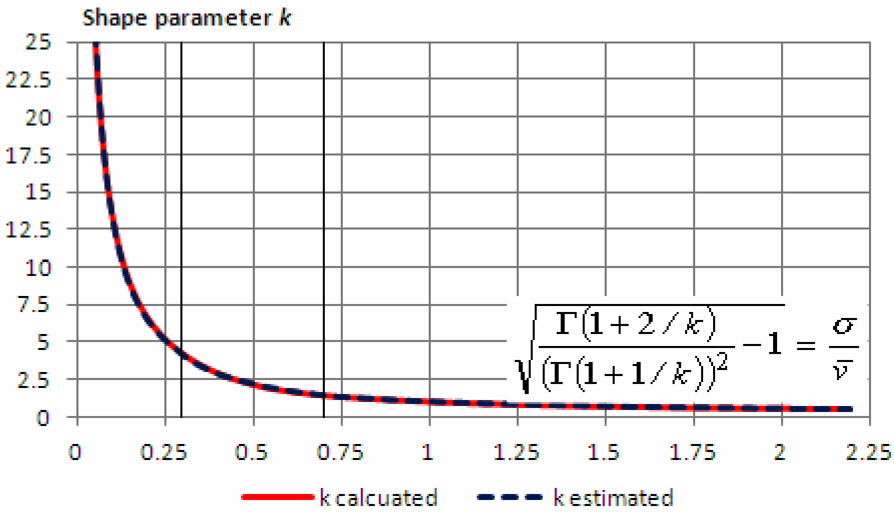


Figure 1. Determination of the shape parameter, *k*

The comparison test of proposed relations for determination of shape parameter, *k*, with respect to its actual values was assessed using three statistical indicators: Mean Percentage Error (MPE), Mean Bias Error (MBE) and Root Mean Square Error (RMSE). These indicators are calculated with the following equations [14]:

$$MBE = \left(\sum_{i=1}^{N}\left(k_{estimated\,i} - k_i\right)\right)/N \tag{17}$$

$$MPE = \left(\sum_{i=1}^{N}\left(\left(k_i - k_{estimated\,i}\right)/k_i\right)100\right)/N \tag{18}$$

$$RMSE = \sqrt{\left(\sum_{i=1}^{N}\left(k_{estimated\,i} - k_i\right)^2\right)/N} \tag{19}$$

where i is the index, $k_{estimated\ i}$ – the i^{th} estimated value of shape parameter and k_i – the actual value of shape parameter calculated from equation (6).
The statistical parameters were calculated for two variation ranges of turbulence intensity values (Table 1), namely:

- between 0.05 and 2.23 that corresponds to values of shape parameter in the limits of range of 25 and 0.5;
- between 0.12 and 2.23 respectively for values of shape parameter between 10 and 0.5.

Table 1. Statistical indicators values (MBE, MPE, RMSE)

Range limits for k	k estimated using technical literature [4, 5, 11]			k estimated using equation (13)			k estimated using equations (14)-(16)		
	MPE (%)	MBE	RMSE	MPE (%)	MBE	RMSE	MPE (%)	MBE	RMSE
0.5÷25	-0.3762	0.1722	0.3313	-0.8372	*0.1175*	*0.2158*	**0.0495**	**-0.0037**	**0.0550**
0.5÷10	0.9932	-0.0137	0.1073	*-0.5826*	*0.0124*	*0.0906*	**0.0041**	**-0.0077**	**0.0466**

The comparison between the statistical test results for the three estimations proposed emphasizes very good results for the estimation of shape parameter using one of the equations (14), (15) or (16).
The MPE and MBE variation, for shape parameter values between 0 and 10 are presented by Figure 2 and Figure 3.
According to the values of MPE and MBE, calculated for k values between 0.5 and 10, the best performance is found at the estimation made using one of the equations (14), (15) or (16). We also mention the estimation achieved using equation (13) leads, for k values between 4 and 10, to a better approximation compared with the approximation made with equation proposed by literature.

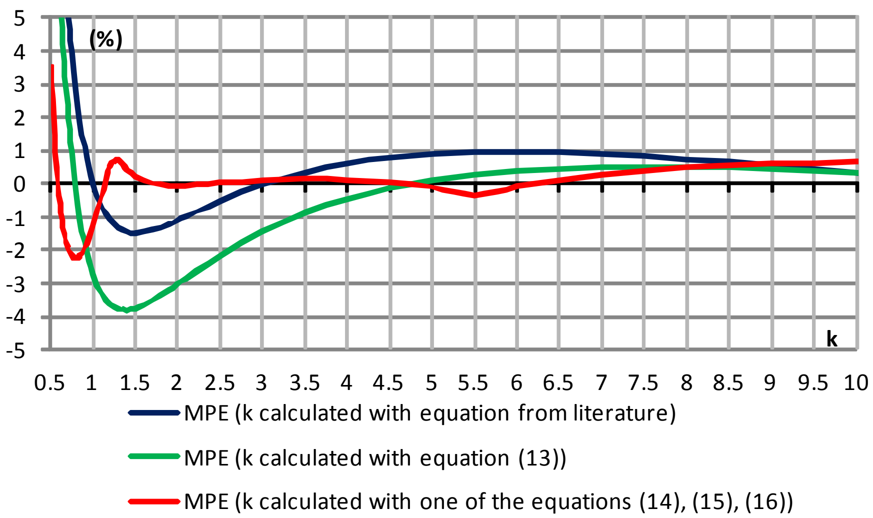


Figure 2. Mean Percentage Error variation for shape parameter k calculated with different equations

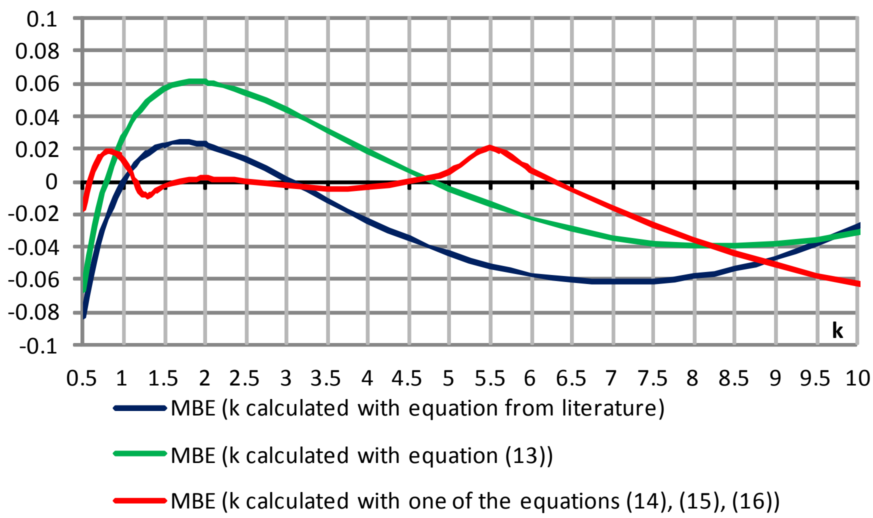


Figure 3. Mean Bias Error variation for shape parameter k calculated with different equations

Taking into consideration those above mentioned the present paper proposes the following algorithm:

- considering the available wind database the following values are determined: the average speed, standard deviation and the turbulence intensity;
- the shape parameter is determined using one of the equations (13)-(16);
- using equation (3), the scale parameter *A* is determined;
- the following parameters can be calculated: the most frequent wind speed (equation (7)), the maximum energetic wind speed (equation (8));
- the wind power density can be estimated using equation (10);
- the Weibull probability density function can be plotted.

3.2 Experimental and computational methods

Braşov is located in the centre of Romania, in Braşov Depression, located at an altitude of 625 m.

As a consequence of the geographical position of Braşov (45.65°N, 25.59°E), this benefits by a temperate continental climate with four distinct seasons: spring, summer, autumn and winter. Local climatic differences are determined mainly by relief and latitude, and less by the oceanic influences from the West, that South-Western Mediterranean and those Eastern continental.

The wind statistics climatology was carried out for two locations in Braşov: one in the town area and the other one in the suburbs area. Therefore, a case study with experimental validation was done, the presented algorithm being applied for the two proposed places of Braşov.

The meteorological data were monitored using two Weather Stations (Delta T), including AN1 anemometers for wind speed and wind direction (resolution and error: 1% ±0.1m.s-1; sensitivity: 0.8Hz per m.s-1).

The first weather station is located in town area, on the roof terrace of the Department of Renewable Energy Systems and Recycling, from Transilvania University of Braşov; this weather station records meteorological data (solar radiation, temperature, the amount of precipitations, wind speed and wind direction) from October 2005.

It is mentioned, the Romanian National Meteorological Administration has installed in the same location a weather station (that works in parallel with Delta-T weather station) for data comparing and validation.

As it can be noticed, the large amount of recorded data makes possible a complete and reliable energy analysis.

The second weather station is installed on the roof terrace of the Research & Development Institute located in the suburbs area. The meteorological database comprises data recorded from January 2013.

At the two weather stations the measurements of both wind parameters, the direction and speed, are carried out, according to recommendations of World Meteorological Organization, at 10 m height above the ground.

Meteorological data management was performed using the Visual FoxPro programming environment. To the choice of software environment for meteorological data processing, the following issue was considered: the large amount of data to be stored and processed makes necessary the use of a specialized database management system, that to make possible the obtaining of specialized results. In this way, there were possible: data management, defining the rules for databases, creating queries using visual design tools, and finally building applications.

4. Results and discussion

Therefore, for the case study there were considered two areas of Braşov, namely: town area of Braşov, for that a weather database corresponding to a period of 8 years is available, and the suburbs area of Braşov, which has weather data for a period about a year and a half.

The results presented further were obtained after processing the entire database available for each weather station (from January 2006 to April 2014 for town area and from January 2013 to April 2014 for suburbs area).

A summary of the monthly values of Weibull parameters (shape and scale parameters) calculated for the measured wind speeds at 10 m, for the two locations of Braşov area (town and suburbs areas) are presented in Table 2.

For the town area, it was found that the monthly values of Weibull shape parameter, *k*, has values in the range of 0.75-1.16. The monthly values of Weibull scale parameter, A, vary in the range of 0.77-1.51 m/s, these corresponding to monthly mean wind speeds values between 0.9-1.5 m/s.

Table 2. Monthly Weibull parameters for Braşov site

Month	Town area		Suburbs area	
	Shape parameter k	Scale parameter A (m/s)	Shape parameter k	Scale parameter A (m/s)
January	0.815	0.924	1.003	1.784
February	0.928	1.021	1.054	1.760
March	0.988	1.520	1.172	2.940
April	0.993	1.293	1.313	2.549
May	1.090	1.348	1.290	2.428
June	1.159	1.409	1.419	1.981
July	1.117	1.433	1.308	2.530
August	1.099	1.151	1.344	1.854
September	0.988	1.135	1.290	3.077
October	0.849	0.776	1.000	1.429
November	0.855	0.895	1.105	1.881
December	0.750	0.805	0.766	1.216

In the case of suburbs area, the monthly values of Weibull shape parameter, *k*, vary between 0.76-1.42, the monthly values of Weibull scale parameters, A, being contained in the range of 1.21-3.05 m/s, thus corresponding to the monthly values of mean wind speeds in the range of 1.5-2.9 m/s.

The monthly probability density functions and the cumulative distribution functions of wind speeds for the two analyzed sites are presented in Figures 4 and 5.

For town area it can be seen a tendency of obtaining the wind speeds around 1.2 m/s, for all the months for the entire year. The monthly peak frequencies range between 47% (in March) and 60% (in August and October), Figure 4.

In the case of suburbs area the monthly peak frequencies are recorded for winds speeds of 1-2 m/s and the range limits are between 20% (September) and 47% (December), Figure 5.

Table 3 presents the monthly values of maximum energetic wind speed calculated using equation (8) and the monthly values of wind power density.

Comparative analysis of the calculated values (based on measured data) and the estimated wind power density shows that the percentage differences between these varies within the limits of -5.4% (September) and 2.24% (January); so it is recorded a slight overestimation of the wind power density.

Comparing the calculated and estimated values of wind power density obtained for suburbs area, the percentage differences are between -4.3% (July) and 4.7% (October).

It is obvious that wind power density values recorded in suburbs area are higher than those recorded for the town area, the highest monthly differences being obtained for the month of September (wind power density for suburbs area is about eight times higher than for town area); the lowest difference was obtained for June.

The annual value of wind power density for suburbs area is about 3.7 times higher than its value obtained for town area.

Figures 6 and 7 show the monthly variation of wind power density depending on the wind speed, for the two areas subjected to analysis.

Considering the town area, the maximum wind power density was obtained during March, the diagram for this month validating the value of maximum energetic wind speed presented by Table 4.

In the case of suburbs area, the maximum wind power density was also obtained for March, values higher than 5.25 W/m^2 being obtained for wind speeds values between 6 m/s and 12 m/s.

It must also be noted the October month with high values of wind power density (higher than 6 W/m^2) for wind speeds between 5 m/s and 9 m/s.

However it should be mentioned that much more important is the study of distribution of wind power depending on wind direction. For this purpose Figure 8 presents the wind power density depending on wind direction (the energetic rose).

For town area, the maximum power wind density is given by the winds from North-East, West, and North-West.

In the case of suburbs area, the rose of wind power density shows as predominant direction, North-West direction. Compared to the town area the wind power density has a more significant value.

The monthly values of wind power density obtained on each sector are presented by Table 4 for town area and by Table 5 for suburbs area.

For the town area, the monthly distribution of wind power density shows a predominant direction from North-East during January, February, May, July and November. The highest value of wind power density is obtained during January, for wind from North-East. A significant value of wind power density is recorded during December, for winds from South-West direction.

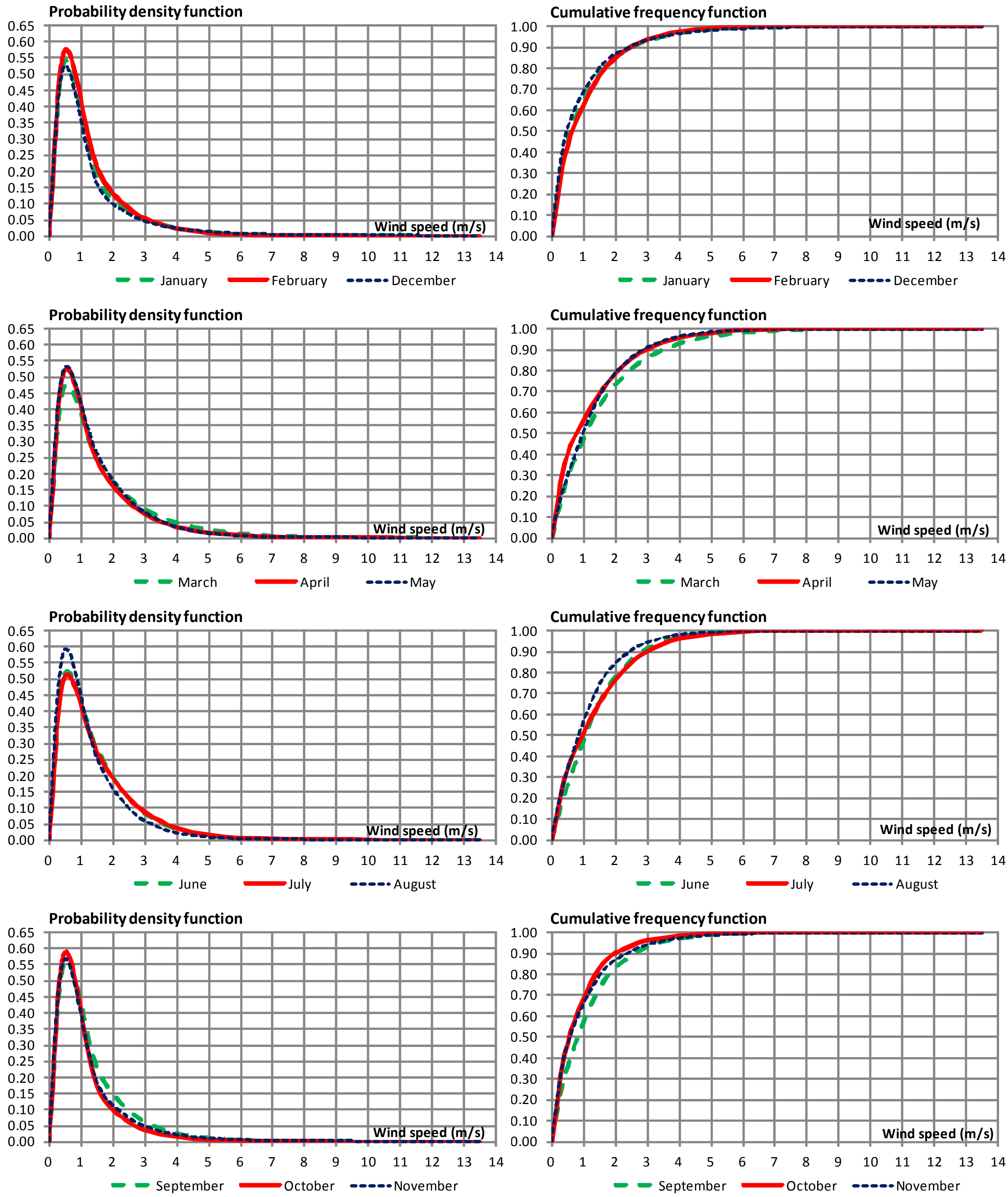


Figure 4. Monthly wind speed probability density and cumulative distribution functions for town area

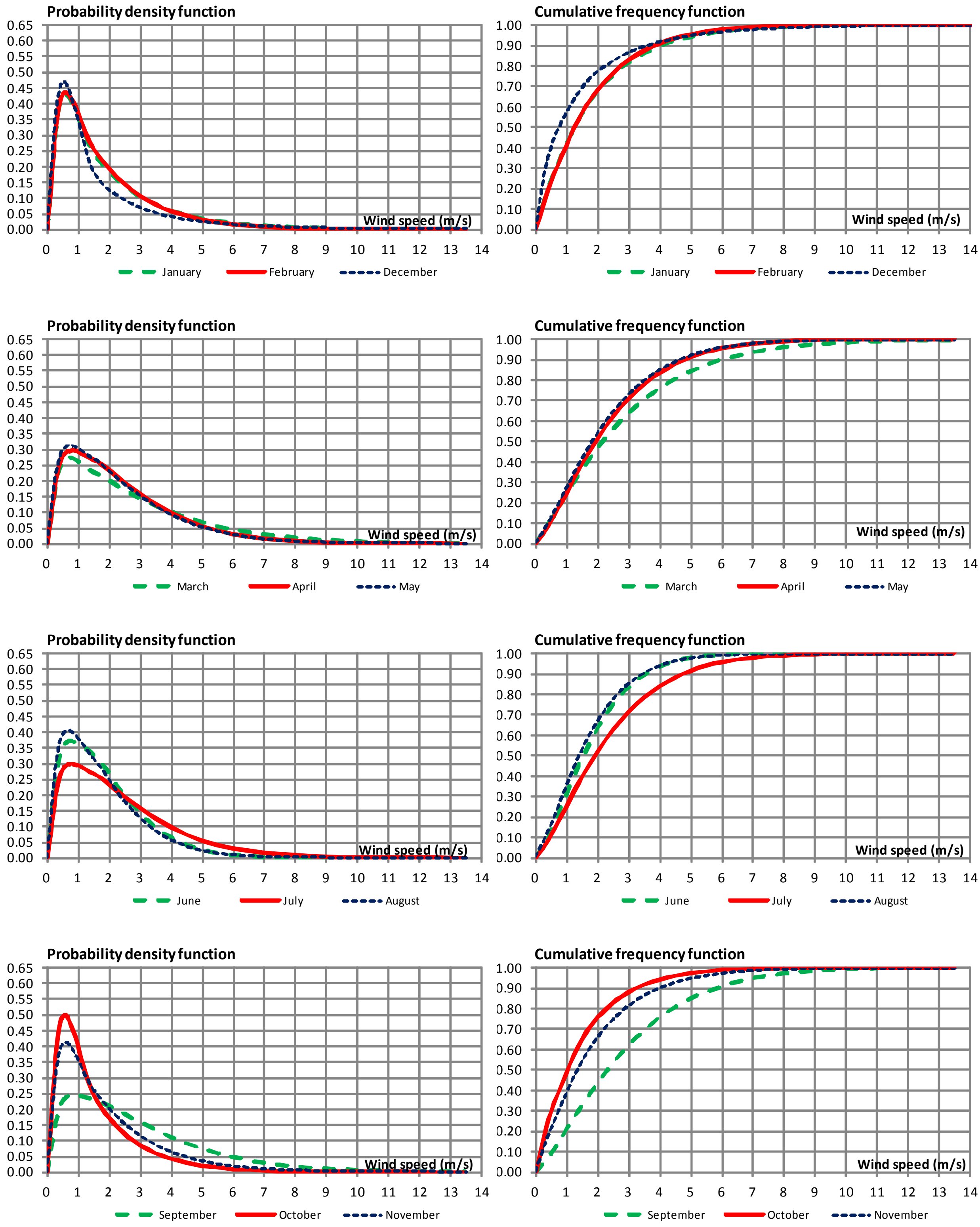


Figure 5. Monthly wind speed probability density and cumulative distribution functions for suburbs area

In the case of suburbs area, for six months (April, June, July, August, September and October) the highest values of wind power density are obtained due to the winds from North-West; five months (January, February, March, November, December) show as predominant direction for the wind power density, the West direction.

The highest value of wind power density is obtained due to winds from West, during March. We mention, during March, important values of wind power density are also obtained due to winds from West and North-West.
Tables 4 and 5 present also the annual values of wind power density depending on wind direction; it is ascertained, the highest values of wind power density are obtained for winds from North-East and North-West if town area is considered; for suburbs area the highest values of wind power density are obtained for winds from West and North-West.

Table 3. Monthly maximum energetic wind speed and monthly calculated and estimated wind power

Month	Maximum energetic wind speed (m/s) – equation (7)		Calculated wind power density (W/m^2)		Estimated wind power density (W/m^2) – equation (9)	
	Town area	Suburbs area	Town area	Suburbs area	Town area	Suburbs area
January	4.23	5.32	7.100	21.425	7.260	20.629
February	3.52	4.83	5.013	19.064	5.200	18.877
March	**4.66**	**6.87**	**12.491**	**56.786**	**12.987**	55.227
April	3.93	5.16	7.807	26.245	8.183	26.798
May	3.51	5.02	6.403	24.049	6.665	24.160
June	3.35	3.68	5.997	10.496	6.283	10.598
July	3.59	5.14	7.052	25.337	7.388	26.444
August	2.96	3.65	3.833	9.921	4.036	9.779
September	3.48	6.36	5.270	**45.894**	5.558	46.164
October	3.23	4.28	3.385	11.323	3.480	10.781
November	3.66	4.79	4.742	17.902	4.925	17.315
December	4.55	6.51	7.187	24.045	7.560	23.402

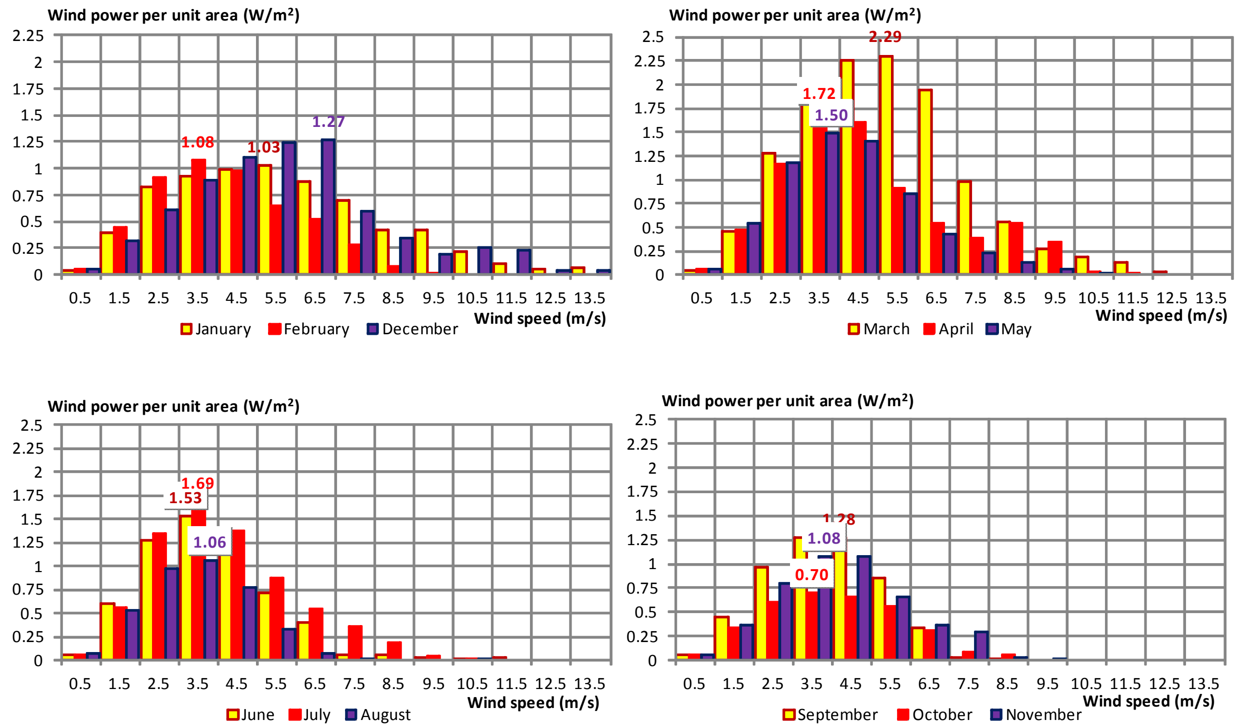


Figure 6. Monthly wind power density for town area

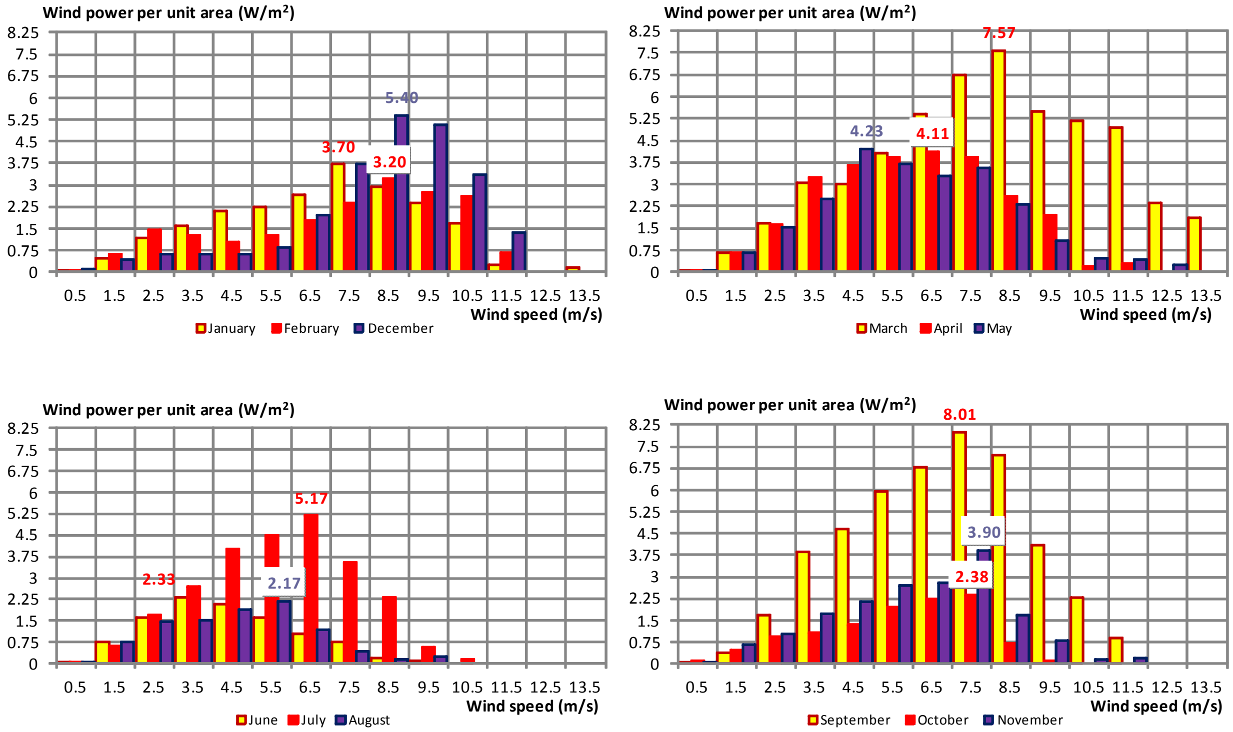
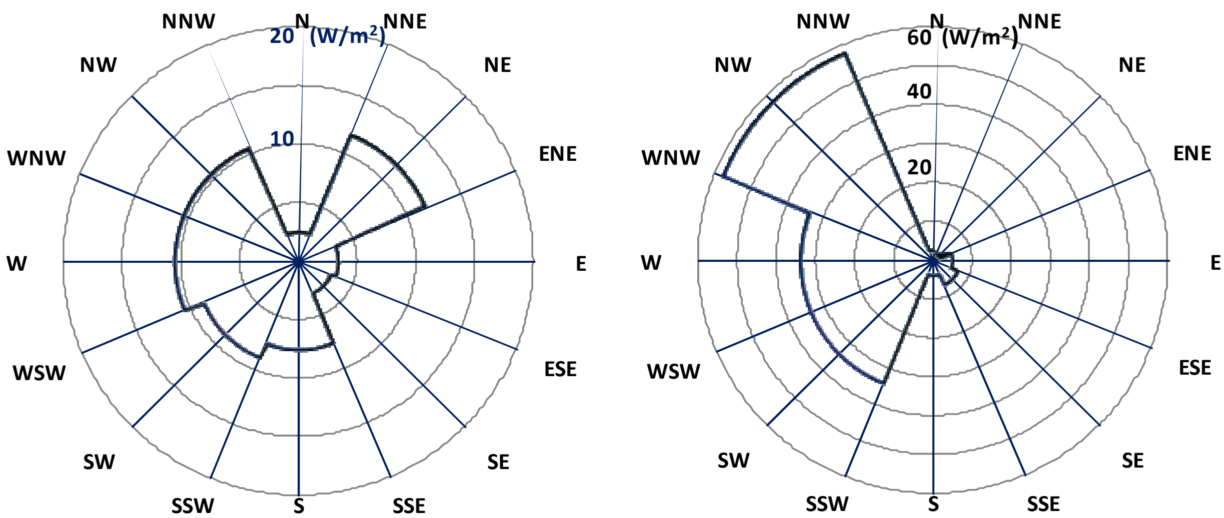


Figure 7. Monthly wind power density for suburbs area



(a) (b)

Figure 8. Wind power density rose: (a) Town area; (b) Suburbs area

Table 4. Monthly values of wind power density depending on wind direction for town area

Month	Wind power density (W/m^2)							
	N	NE	E	SE	S	SW	W	NW
January	0.51	**28.12**	3.55	2.15	0.91	4.93	8.15	5.32
February	2.67	**10.19**	4.11	3.17	2.56	5.17	5.40	7.13
March	6.97	14.90	4.98	3.43	4.61	17.36	**19.25**	**20.88**
April	3.22	13.21	5.04	4.34	2.51	5.63	10.77	**19.71**
May	3.06	**11.39**	5.09	4.50	3.78	7.51	5.80	9.83
June	3.79	10.68	3.98	3.29	1.98	5.99	6.38	**12.03**
July	1.53	**17.28**	3.69	3.39	1.92	4.26	7.51	12.32
August	2.82	3.61	1.26	1.88	2.51	3.32	4.83	**10.00**
September	1.53	7.48	1.82	1.71	2.71	3.11	**9.72**	**9.88**
October	0.32	2.76	1.53	1.21	1.17	6.75	5.39	6.59
November	0.26	**7.59**	2.28	2.80	1.97	7.22	**7.86**	5.18
December	1.10	2.43	3.02	3.18	9.23	**19.37**	10.38	5.84
Annual values	2.54	**11.67**	3.35	2.91	2.90	7.48	8.80	**10.54**

Table 5. Monthly values of wind power density depending on wind direction for suburbs area

Month	Wind power density (W/m^2)							
	N	NE	E	SE	S	SW	W	NW
January	1.14	1.00	4.81	7.19	1.35	29.69	**49.50**	46.30
February	1.80	1.61	4.94	4.46	1.19	44.43	**44.65**	23.26
March	2.04	4.66	7.92	8.75	11.14	83.82	**133.44**	104.96
April	9.29	1.96	8.16	13.67	3.88	44.39	40.92	**50.91**
May	2.75	5.28	5.95	17.16	9.12	**42.84**	36.27	33.11
June	6.25	1.53	2.58	2.49	2.20	14.30	16.00	**19.56**
July	8.38	1.48	3.34	6.56	3.06	9.65	35.99	**69.92**
August	0.21	1.94	2.36	3.87	4.24	10.92	19.66	**33.18**
September	4.54	0.74	2.98	2.11	3.13	24.00	76.65	**82.07**
October	0.23	0.66	1.62	1.89	0.90	19.51	19.78	**43.93**
November	1.18	0.99	4.49	3.70	2.71	38.00	**43.48**	25.11
December	1.46	0.42	1.03	1.58	0.94	2.70	**75.55**	40.62
Annual values	2.70	1.72	4.86	6.75	3.73	33.81	**57.70**	**53.62**

5. Conclusions

The wind variability also implies the variability of generated electricity. This is the difference compared to the most sources of conventional energy where the fuel is usually kept constant. The primary source of energy in producing wind energy does not have a constant flow.

The site climate describes this variability statistically. Different sites have different wind climates; the wind energy dependence of the cube of wind speed leads to variation of annual average power depending on site.

The geographical position of Braşov, in the internal curvature of the Carpathian, at the junction of the Southern Carpathians, the Eastern Carpathians and the Transylvanian Plateau, induces a high variability for the spatial distribution of wind parameters.

Braşov area is characterized by the monthly values of mean wind speeds ranging between 0.9 m/s (October) and 1.55 m/s (March). In order for an area to be viable for wind power turbines installation, this must have a minimum mean wind speed of 4 m/s at a height of 10 m above the ground.

Considering this aspect, the Braşov town area does not fit in the category of areas with significant values of wind potential.

Regarding the suburbs area, this is characterized by the monthly values of mean wind speed between 1.5 m/s (October) and 2.9 m/s (September); therefore the suburbs area does not fall into the minimum speed limit for that this could be taken into account.

However, given the significant values of wind power density obtained for the suburbs area and taking into account the following aspects:

- the influence of different local factors that can lead to the intensification of wind speed on small areas (for example the effect of speed-up due to the hills),
- the anemometric data measure the wind speed at a height of 10 m above the ground, but if it is taken into account the increasing of wind speed with the height above ground, its values can increase significantly (it is mentioned, the towers of modern turbine have heights of at least 60 m [6, 7]; so high towers are needed to raise the wind turbine above the turbulence generated by obstacles on the ground and trees),

then the studies development may lead to the identification of locations that may be exploited in view of electricity production.

Therefore, an investment in wind field and the concrete indication of the placement location of wind turbines are made as a result of a detailed study of available wind potential.

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