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INVESTIGATION OF THE WIND POWER POTENTIAL OF THE HERNÁD VALLEY

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Abstract
The University of Debrecen, Department of Meteorology has carried out research into the climatic and social-economic conditions of the Hernád valley in the scope of a scientific project (OTKA K 75794) between 2009 and 2012. The aim is to find out the optimal area for wind and solar energy, as well as biomass utilization. Our purpose is to work out a model wherein the complex evaluation of natural and social-economic conditions and effects can eventually result in a sustainable and conflict-free land use. The results of the research will be useful in working out a regional improvement based on the use of renewable energy sources to help the local decision-making process.

Keywords: statistical climatology, Hernád valley, wind profile, wind potential

1. Introduction

Examining the climate of smaller regions always serves the solution of a practical problem. The character of use determines the importance and soundness of a climatologic description but these descriptions are often used for background information in other research. It is not an easy task since for smaller areas observational data covering the longer and shorter term are very rare. The lower course of the Hernád River valley in Hungary is a lesser known region from a climatologic perspective, especially regarding wind conditions.

Our area under examination belongs to the Northern Mountains climatic zone (Bartholy and Weidinger, 1997) which includes various microclimatic regions, with plentiful precipitation-cool summer mountainous, and warmer-drier inner basins and highlands. Determining the climatic zones of Hungary Péczely (1979) used a classification that characterizes the water- and heat supply based on the average temperature of the aridity index and vegetation period. He categorized the northern areas of the Hernád valley as a temperate cool-dry climate, while the southern regions as a temperate hot-dry climate.

The Hungarian Meteorological Service (OMSZ) operates a regional centre for meteorological observations in Miskolc, where the calculated mean annual temperature is 9.6°C, the annual average precipitation is 533 mm and the annual hours of sunshine are no more than 1,797 based on a 30 year long period running from 1971 to 2000. The estimated annual average wind speed is between 2 and 2.5m/s.

The Hernád valley runs north-east and south-west between Cserehát and the Tokaj Hill creating a natural contact between the North-western Carpathians and the Great Plain. Based on its geographical position and relief we suppose that it creates a natural direction for the air movement from the Eastern Beskid and participates in local air exchange between mountain and plain areas (Dobosy and Felméry, 1994; Péczely, 1976). The Hernád valley certainly affects the direction of air movements - the wind from Kassa is often called 'the Kassai wind' by the people living along the border. In this article we present our preliminary statistical wind climatological results in this region, based on our wind measurement program which was carried out in 2010.

2. Methods

With the aim of researching wind climatology a 20m high wind mast was set up in the north part of the Hernád valley to measure wind direction and wind speed profile. The station is situated to the west of Hidasnémeti, 500 meters from the edge of the settlement (Fig.1); the geographic latitude and longitude are 48°30'N and 21°13'E, and the station is 179 m above sea level.

The datalogger (which was made by Ammonit Gmbh) collects 10 minute average wind speeds at heights of 10m and 20 m above surface, and wind direction at a height of 10 metres. We used optically scanned cup anemometers and a wind wane (without heating). The manufacturer of the instruments was Thies and the anemometers comply with all the requirements of IEC 61400-12-1 (2005-12). In this article we present the results of the dataset between 24 April and 5 December 2010.

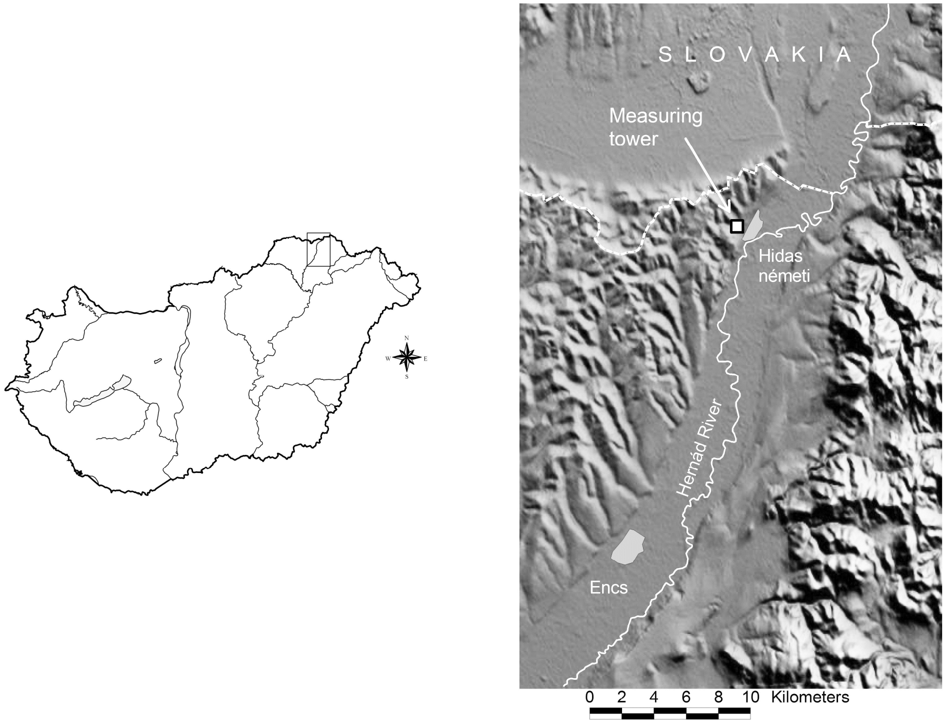

Fig. 1 Geographical position of the wind mast used in the research.

3. Results

1.1 Basic statistics

The average wind speed for the complete period of our measurement is 3.0 m/s at 10 m and 3.4 m/s at 20 m. Thus it is also higher at a lower level than the 2 m/s long-term climate-average mentioned above. Standard deviations equal to 1.5 and 1.4 m/s, namely the variation coefficients (standard deviations/mean) are 0.50 and 0.41 respectively. In other words the wind speed at a higher level is less variable than at 10 m. Monthly averages are shown in Fig.2.

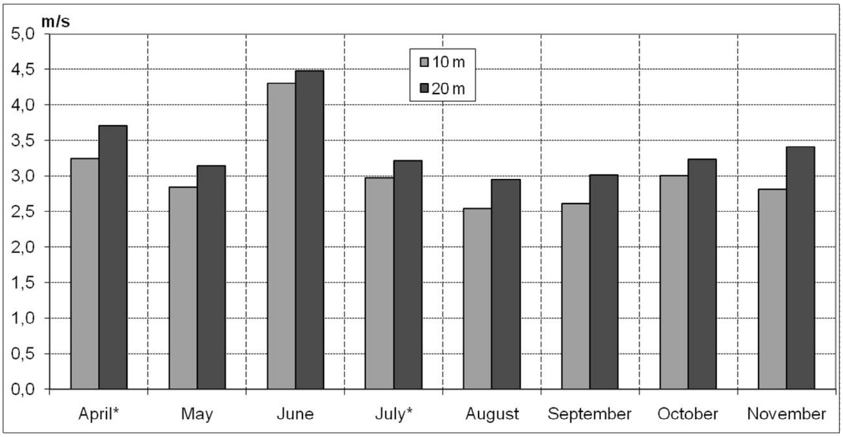

Fig. 2 Average wind speed values (*- whole month data not displayed because of instrument error in April and in July)

According to Fig.2 wind speed at both heights is highest in June. The difference between the averages of the two heights is the greatest (0.6 m/s) in November.

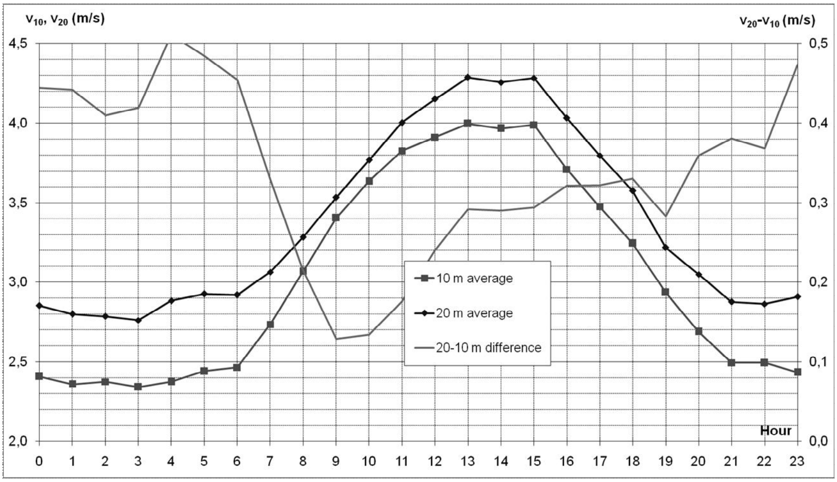

Fig. 3 Diurnal course of wind speed averages per hour

Diurnal variations of hourly averages and the differences between them can be seen in Fig.3. The maximum average wind speed at both heights occurs between 1 and 3 pm, while the minimum is between 1 and 3 am, which corresponds to the Hungarian wind climate. The diurnal fluctuation at 10 m is 1.7 m/s, and at 20 m is 1.5 m/s. This indicates that the wind speed at the higher level has smaller diurnal amplitude. The difference between the average values of wind speeds at the two heights is greater by 0.1-0.3 m/s at night-time; the minimum (average) speed occurs within 1-2 hours after sunrise. There are different results in summer and in autumn: average summer wind speed is 3.3 m/s at 10 m, with a fluctuation of 1.8

m/s, and 3.6 m/s at 20 m, with a fluctuation of 1.7 m/s. Values are lower in autumn: the averages are 2.8 and 3.2 m/s and the fluctuations are 1.6 and 1.3 m/s respectively.

The diurnal variations in hourly averages and their differences in two seasons (summer and autumn) can be seen in Fig.4. The diagram shows that at both heights the maximum wind speed sets in at around 2 pm in summertime and at around 1pm in autumn. At nights, the average speed at 20 m in autumn exceeds that measured in summer at 10 m. The ranking during the day is the following: summer at 20 m, summer at 10 m, autumn at 20 m, autumn at 10 m. There is no difference between the variance amplitudes: they are 0.4 m/s in both seasons. However, diurnal courses of variance differ substantially from each other; for instance they can be about 0 in the early and morning hours in summer.

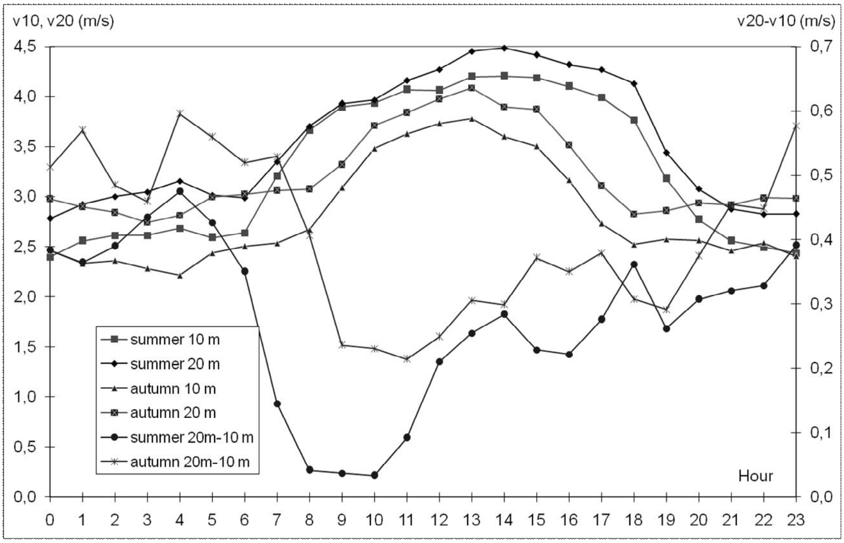

Fig. 4 Diurnal variation of average wind speeds per hour in summer and autumn

1.2 Wind speed-change with height/wind profile

The examination of the differences between the two levels is important in terms of extrapolating the results to higher altitude. The so-called Hellmann-equation describes the change of wind speed with height in wind energetic:

$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^{\alpha}, \qquad (1)$$

where v_1 is a wind speed at h_1 elevation and v_2 at h_2 elevation, the α exponent depends on the balance of ground roughness and the stability of the air. Because of the latter it is temperature-dependent and so has a diurnal and seasonal course.

Generally in the location of the planned wind power station the average value of α can be determined from long term wind speed measurements at two heights. One of the heights is expediently 10 m thus the survey data can be comparable with data from the nearest meteorological station where this height is required. A height above 10 m is theoretically optional but a height of 20-30 m is practical to minimize expenses. After determining the average value of the α exponent the mean wind speed of any other height can be estimated by the formula above.

Based on the calculations from our data the mean exponent concerning the whole period is 0.19. This corresponds to the 0.2 value that is ordinarily used for the country areas, independently of seasons. Different authors suggest different values depending on ground roughness. According to Aujeszky (1949) a good approach can be achieved by a α=0.2 value up to 250m. Ledács-Kiss (1977, 1983), Tóth et al. (2001) and Patay (2001a, 2001b, 2003) used this form. However, based on the data from meteorological towers and energetic wind measures the value of α can be specified according to surface friction. According to Kajor (2002) the value changes from 0.14 (over smooth sea surface) to 0.34 (over rough land surfaces). According to Radics (2004) the exponent value is 0.14 over flat terrain and bodies of water, 0.2 over rough, hilly areas, and reaches 0.28 over settlements. The most detailed data for the exponent can be found in the work of Sembery and Tóth (2004) who gave values of 0.12 over flat country, 0.16 over open country, 0.25 over wooded plains, 0.35 over settlements with low buildings and 0.50 over settlements with high buildings. At the same time, in accordance with Péczely (1979) the α exponent depends on wind speed and thermal stratification of the atmosphere in addition to surface roughness. For example it is 0.3 over grasslands in the case of daily, monthly, yearly average wind speeds. According to the latest research concerning Hungarian wind and solar energy, the use of a 0.25 exponent is suggested for national calculations (Dobi and Mika, 2007).

As mentioned above α is temperature-dependent in accordance with atmospheric stability, which means that in the case of low surface temperature (stable conditions) the value is higher, while during high surface temperature (unstable conditions) the value is lower (Radics, 2004). This is illustrated in Fig.5 where monthly average values of the exponent are shown. The lowest values can be seen in the first two summer months (even though the values for May and October are close to it) and the highest are in November, probably in the coldest month of the period. Seasonal values are more convincing: the exponent average is 0.17 in summer and 0.22 in autumn.

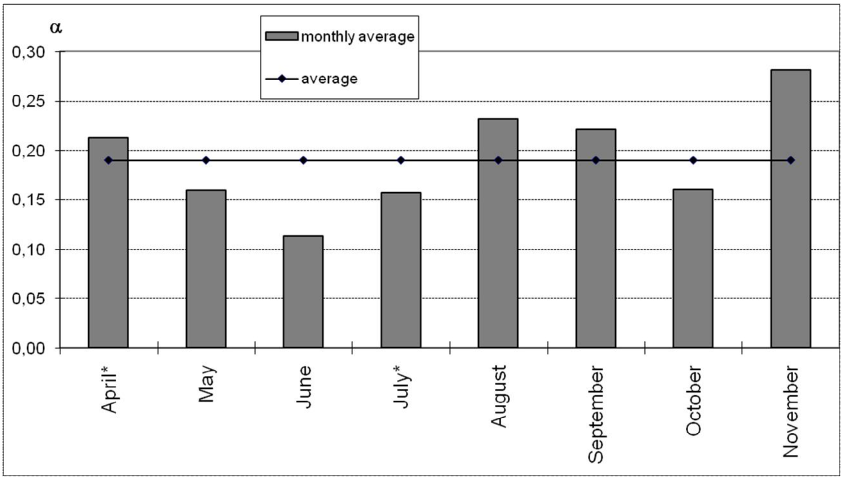

Fig. 5 Monthly and whole term average values of the Hellmann exponent
(*- whole month data not displayed because of instrument error in April and in July)

According to Péczely et al. (1979) the exponent also depends on wind speed. On the basis of Figs.2 and 5 the linear correlation coefficient between the monthly averages of α and the 10 m wind speed is -0.6581, which means that the stochastic correlation can be considered as real at the 0.1 significance level.

Monthly averages were determined at 20 m, 50 m and 100 m from 10m monthly average wind speeds in Fig.6 using the data from Figs.2 and 5. The error of the 'Hellmann-model' can be determined from the data measured and counted at 20 m. Its maximum - 4% - is in June, the minimum - 0.4% - is in November and the average is 2%.

The average diurnal course of α has to be known to produce the average diurnal course of the wind speed at a certain height. The diurnal course of the wind speed usually shows the characteristics observed in Figs.3 and 4 only at the lower height of 60-80 m; above this height it turns: night maximums and 1-2 pm minimums are experienced. Calculating with a constant exponent this diurnal course does not re-occur.

The exponent and the hourly averages of 10 m wind speeds are illustrated together in Fig.7. According to the opposite diurnal course, the stochastic correlation of wind speed and α can be best described with a decreasing power function. In this case the correlation coefficient value is the highest at 0.9166 (Fig.8).

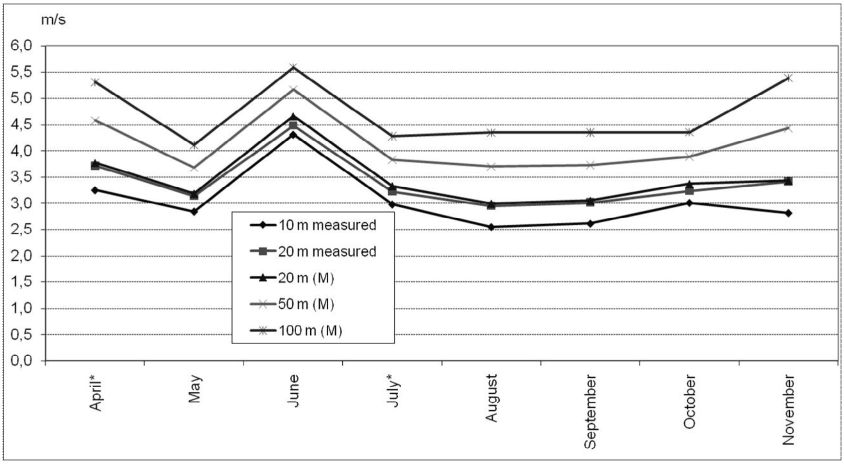

Fig. 6 Monthly average wind speeds measured at 10 m and 20 m, modelled (M) at 20 m, 50 m, 100 m

The diurnal course of α follows the diurnal course of 20 m and 10 m hourly wind speed differences (Figs. 3 and 4), i.e. the value is extreme between 3 am and 6 am. According to other examinations night values are higher but less changeable than those in the morning. A regular diurnal course can be seen in Fig.9 which was made up from whole year measures (Tar, 2004, 2007a). The difference from this is caused by our ‘incomplete’ data base.

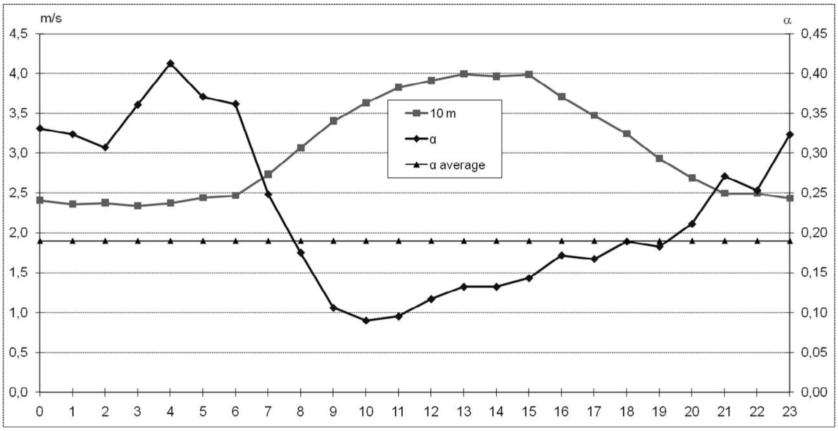

Fig. 7 Diurnal course of the average Hellmann exponent (α) and average wind speed at 10 m

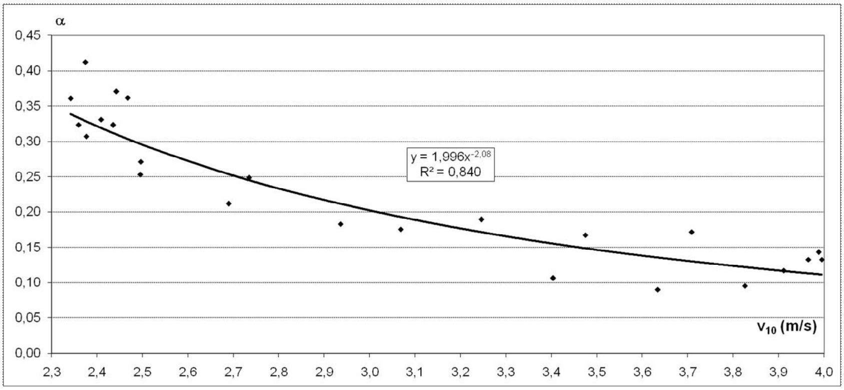

Fig. 8 The relationship between the Hellmann exponent (α) and the hourly average wind speed at 10 m

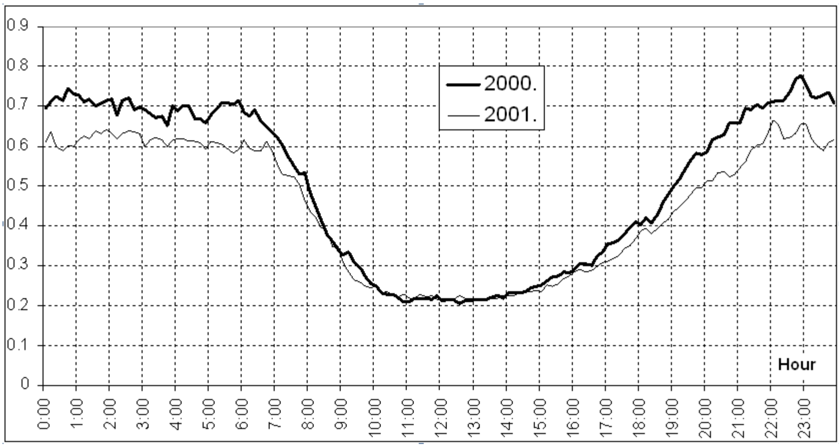

Fig. 9 An example of the regular diurnal course of the Hellmann exponent (Paks, 2000 and 2001, calculated from 20 m and 50 m wind speeds)

According to the diurnal course of α, the average diurnal course of wind speed at heights higher than the measured levels can be produced. This is decisive in terms of potential wind energy quantity. Our experiment referred to heights of 50 m, 100 m, 150 m and 200 m as is shown in Fig.10. It can be seen that the previously mentioned inverse diurnal course (maximum at night-time) does not occur, not even at 200 m; however wind speeds at dawn definitely increased.

Besides the incomplete data base, the reason for this irregular diurnal course can be caused by orographic factors that can accelerate the winds at 20 m height in these hours. Our own data base of measurements of wind directions over a much longer period and a detailed analysis of wind data from an adjacent meteorological station can help us to make a decision.

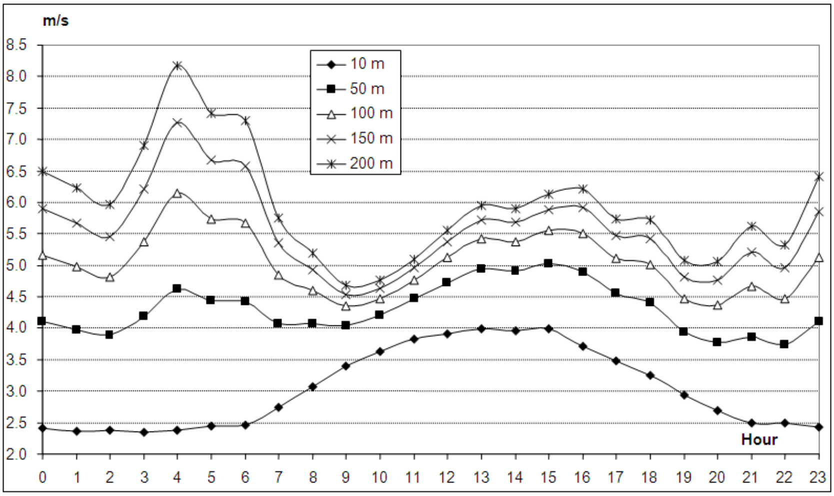

Fig. 10 Diurnal course of wind speed measured at 10m and modelled in different heights according to the diurnal variation of the Hellmann exponent

1.3 Definition of diurnal average specific wind potential

Specific wind potential is the kinetic energy of an air mass that passes through a 1 m^2 vertical surface in 1 second. It can be calculated at a definite moment with the following formula:

$$P_f = \frac{\rho}{2} v^3 \tag{2}$$

where ρ is air density and *v* is wind speed. The total specific wind potential of a definite period, e.g. a day, can be determined from wind speeds measured at certain times of the term. There are two possibilities: either we change *v* in equation (2) for the average wind speed of the term, or we add up the values obtained in each (discreet) time of the term. Logically, the second option is closer to reality. However, the dependence of the sum on the number of the term moments causes the problem. This dependence can be reduced by averaging, but cannot be completely eliminated. The value of the 'average diurnal specific wind potential', which actually means an average potential for an hour of the day, is also not independent of the numbers of the times considered (hours). Moreover, it depends on what times we have worked with.

However, there exists a principled solution to avoid this dependence: we have to determine the under-curve-area of the function that gives the diurnal variation of wind speed-cubes and multiply by ρ/2. Thus, we can obtain the exact value of the total specific wind potential. Of course we can only do this with numerical integration since the function usually cannot be specified analytically. However, we can attempt to determine the average specific wind potential (P_{fmd}) regarding a given term (e.g. month, season, year) which consists of days, with the help of an approximating function, since it can be seen that P_{fmd} is equal to the sum of wind speed cube averages per hour, multiplied by $\rho/2$.

Thus hourly wind speeds (0, 1, 2, ..., 23) for every single day of a period are given. We can define the average specific wind potential for a single day of the term in the following equation: multiply half of the air density and the under-curve-area of the function approximating the diurnal course of wind speed cube averages per hour. Let the approximating function be the following:

$$f_2(x) = a_0 + \sum_{m=1}^{2}(a_m \cos\frac{2\pi mx}{N} + b_m \sin\frac{2\pi mx}{N}) \tag{3}$$

namely, the first two elements of a Fourier series that consist of trigonometric polynomials, where N=24, x=0, 2, …, N-1.

The correctness of the approximation can be given by the so-called residual variance:

$$s_m^2 = s_{m-1}^2 - 0.5A_m^2 \tag{4}$$

where $s_0^2 = s_n^2$, that is variance, A_m is the m-wave amplitude. It is evident that s_m^2 depends on the number of the elements, which is why it is not suitable for comparison. Because of this we defined the relative index of approximation correctness.

$$s_{0m} = \frac{s_0^2 - s_m^2}{s_0^2} \tag{5}$$

that is between 0 and 1, the maximum occurs in the case of a ‘perfect’ fit.
The primitive function of the function (3) is the following:

$$F_2(x) = a_0 x + \sum_{m=1}^{2}(\frac{a_m}{\alpha_m}\sin\alpha_m x - \frac{b_m}{\alpha_m}\cos\alpha_m x) \tag{6}$$

where $\alpha_m = \frac{2\pi m}{N}$. If we use the timeline of hourly wind speed cube averages for determining the a_m and b_m factors, the average specific wind potential for a single day of the term is:

$$P_{fmd} = \frac{\rho}{2}[F_2(23) - F_2(0)] \tag{7}$$

where $F_2(23)$-$F_2(0)$= T_{ga} is the under-curve-area (Tar, 2004, 2007a, 2007b) .
The monthly averages of wind speed and wind speed cubes, the deviation of the latter, the monthly index of the approximation correctness and the under-curve-area can be seen in Table 1. According to the table the best approximation occurs in April and September, but it is quite slight in November. There is probably a linear correlation between the average wind speed, as well as the wind speed cube average and the under-curve-area (which is proportional to the average specific wind potential for a single day of the term). This statement, which seems trivial, does not result from a complicated, analytically inexpressible relation to this quantity.

Table 1. Monthly average and standard deviation of wind speed and wind speed cubes, the index of the approximation correctness and the monthly values of under-curve-area at a height of 10 m.

	10 m				
	mean wind speed	cube of wind speed	cube of standard deviation	fitting	T_{ga}
April*	3.3	77.3	72.3	0.95	1849.3
May	2.8	60.5	42.7	0.85	1419.2
June	4.3	223.4	64.2	0.75	5213.5
July*	3.0	67.5	29.5	0.72	1589.7
August	2.5	38.4	23.1	0.86	912.7
September	2.6	43.3	29.7	0.96	1023.9
October	3.0	94.0	32.9	0.82	2182.0
November	2.8	47.7	15.4	0.57	1093.0

Raising both sides of the equation (1) to the third power we obtain the dependence of the wind speed cubes on height. Thus, their proportion is given by raising the proportion of the heights to the 3α-power. Wind speed cubes for higher levels can be calculated from hourly wind speed cubes determined from the data measured at 10 m. As a first step we disregard the diurnal course of α, considering only the monthly changes in it. A height of 60 m was chosen as an example, where the diurnal course trend of wind speed probably corresponds to the diurnal course of 10 m. In Table 2 we can see the monthly average and the standard deviation of hourly wind speed cubes at 60 m, as well as the index of the approximation correctness and the under-curve-area. Comparing with Table 1 it can be observed that the monthly speed averages, and the increase of under-curve-area which is proportional to the monthly average specific wind potential, are changing by the month. This results from the monthly difference in the exponent. The maximum increase of under-curve-area can be observed in November, its value is 4.5 times higher than the value experienced at 10 m. However, this proportion is only 1.8 in June.

Table 2. Monthly average and standard deviation of wind speed and wind speed cubes, the index of the approximation correctness and the monthly values of under-curve-area at 60 m height.

	60 m				
	mean wind speed	cube of wind speed	cube of standard deviation	fitting	T_{ga}
April*	4.7	239.1	223.5	0.95	5717.9
May	3.8	142.9	105.2	0.78	3353.9
June	5.2	403.4	116.9	0.74	9417.2
July*	4.0	159.6	66.8	0.78	3756.8
August	3.8	132.1	78.0	0.90	3142.3
September	3.9	141.3	97.0	0.96	3340.8
October	4.0	222.2	78.1	0.70	3685.4
November	4.7	214.9	63.1	0.68	4923.3

The average diurnal course of wind speed cubes relating to the whole period can be seen in Fig.11 at the two heights mentioned above. According to the figure the difference in potential energy can be regarded as constant during night hours; in the morning it increases until 1-2 pm and starts decreasing later. The under-curve-area fitted to these diurnal courses - namely the diurnal average specific wind potential - is 3.7 times higher at 60 m than at 10 m.

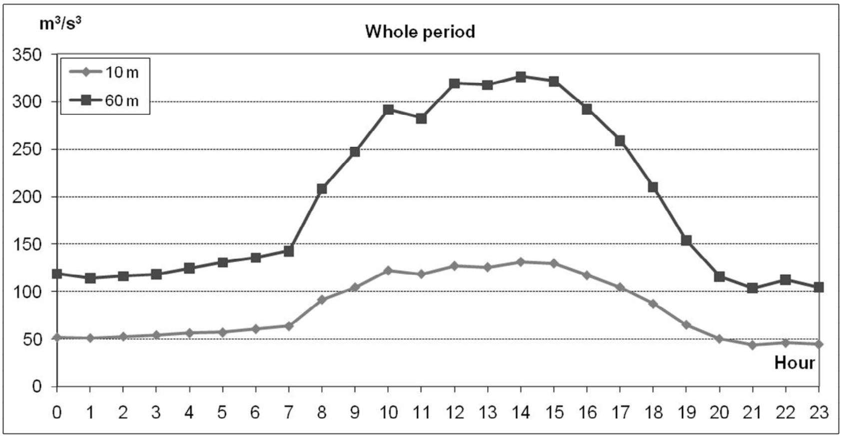

Fig. 11 Average diurnal course of wind speed cubes at 10 m and 60 m for the whole period

4. Conclusion

The measured parameters show that despite the temporal fluctuation the use of wind energy in the area can be appropriate and efficient, principally in the case of wind power plants with low speed start-up or wind engines. We could not entirely solve all the problems during the analysis of our short data base. Besides continuous monitoring and processing it is necessary to control our data with the data of one or more meteorological stations, close to Hidasnémeti, if possible.

5. Acknowledgements

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