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Estimation of solar and wind energy potential in the Hernád Valley

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Abstract—This paper focuses on the climatic conditions of the Hernád Valley with the purpose of exploring on what level the utilization of wind and solar energy is advanced or detained in the micro-region. For determination of wind and solar energy potential, an automatic weather station was mounted in the Hungarian section of the Hernád Valley located on a small hill 500 meters west from the settlement of Hidasnémeti.

Available long-term surface global radiation data do not represent our study area on regional scale. For this reason, daily global radiation datasets of the nearest weather station, the airport of Kosice has been used for the analyses. Diurnal and annual variation and spatial pattern of global radiation have been examined by combination of statistical analyses and geo-information/GIS methods.

Other important aim of the research is to describe the spatial characteristics of the wind energy potential related to orography in the Hernád Valley. Diurnal courses of different statistical parameters and the spatial pattern of wind speeds has been investigated on the base of our measured data. Since these data are not continuous, relationships between the diurnal average wind speeds of Kosice and Hidasnémeti were examined also. An attempt has been made to complete our diurnal average wind speed database by linear regression.

Finally, the social and economic conditions regarding solar and wind energy utilization are mentioned shortly in the paper.

Key-words: Hernád Valley, solar energy potential, wind profile, wind energy potential

1. Introduction

The Department of Meteorology, University of Debrecen carried out the research of the climatic and social-economic conditions of Hernád Valley in the frame of a scientific project between 2009 and 2012. The aim was to find 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 result in a sustainable and out-of-conflict land use, after all. The results of the research will be useful to work out a regional improvement strategy based on the use of renewable energy sources to help local decision process. Most important results of investigations on wind and solar climate and energy are summarized in this paper. Local conditions can serve as a good base for further development of solar energy utilization in the region. Solar energy can be introduced in some new fields like ecologic and silvicultural applications. Our examinations have showed also that in spite of temporal fluctuations, utilization of wind energy in the study area can be expedient and effective, especially in the case of application of low starting speed wind turbines. Citizens' opinion about instruments of utilization of solar and wind energy is positive, and they are open for such initiatives. Well prepared projects can be successful and can contribute to the development of the economy of the region.

This research intends to focus on the climatological conditions of the Hernád Valley micro-region with the purpose of exploring on what level they advance or detain the utilization of solar and wind energy.

As a first step, the exploration of the climatological endowments of the selected area based on climatological observations was carried out. It made possible the calculation of indexes, which describe the connections between weather types and the amount of utilizable wind and solar energy on one hand, the elaboration of a model, that helps the allocation of wind turbines and refining of relations, as well as describes the variations of wind speeds with height; and selection of plants optimal for biomass production in a given micro-region on the other hand. Social-economic studies focused on financial benefits and cost-efficiency indexes have been revealed, as well as social acceptance of renewable energy sources have been surveyed.

For determination of wind and solar energy potential, an automatic weather station was established in the Hungarian section of Hernád Valley on a small hill 500 meters west from the settlement of Hidasnémeti at N 48°30’ and E 21°13’ at a height of 175 meters above sea level (*Fig. 1*). The automatic weather station was mounted on a 20-meter high measurement mast which was equipped with a wind direction sensor at a height of 10 meters and two anemometers at heights of 10 and 20 meters among other instruments.

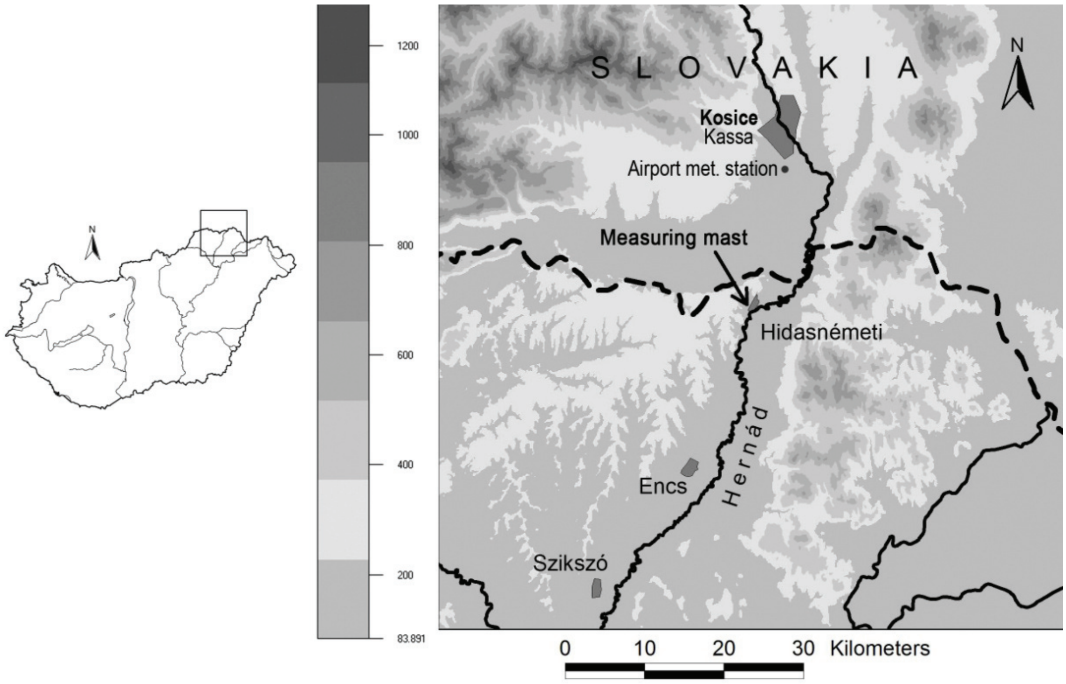

Fig. 1. Geographical situation of the meteorological measurements.

To survey the solar energy potential of the Hernád Valley, it is important to know the temporal and spatial pattern of global radiation of its region. It is determined by the Sun and the geometry of the relief; however, actual atmospheric conditions have an important effect on the amount of incoming solar radiation as well. Available surface global radiation data do not represents our study area on regional scale. For this reason, daily global radiation datasets of the nearest weather station, the airport of Kosice (48.667°N, 21.217°E, 231 m a.s.l.) have been used for the analyses.

Datasets have gone under statistic-climatological analyses, main statistic parameters have been determined, wind speed and direction frequency distributions have been prepared for both heights; hourly and diurnal average values of the parameter in the Hellman wind profile equation have been determined in the first stage of our wind climatological research. On this base, average diurnal courses and diurnal average wind speeds for levels higher than the measurements levels have been calculated, what is decisive from the aspect of the amount of potential wind energy. A statistic definition has been worked out for diurnal average specific wind power of a day of any period of time. Its comparative examination has been carried out as well.

However, the survey of wind potential of the Hernád Valley requires spatial extrapolation as well. The model used for this purpose is not our development, but there are not any examples for Hungarian adaptations of the WindSim 5.1 EV model yet. The model has a modular structure, and it generates the spatial distribution of average wind speeds influenced by orography in successive steps, what determines the prospective energy production of the chosen wind energy utilizing instrument practically. Turbulence parameters influenced by orography and spatial patterns of wind speeds weighted on the base of average wind direction distribution have been determined for the Hernád Valley using both the results of our measurements and the one-year-long dataset from the airport of Kosice, eventually. Wind potential maps can be generated for any heights up to 200 meters. They can help the selection of optimal sites for wind energy utilization.

2. *Examination of solar energy potential in the Hernád Valley*

To determine the solar energy potential of the Hernád Valley the first step is to gain information on temporal and spatial pattern of global radiation of that region. Since there is not any Hungarian long-term surface radiation measurement stations in the environment of our study area, diurnal global radiation datasets of the nearest weather station, the airport of Kosice (Slovakia) have been used for the analyses.

Besides the pointwise measurements, ArcGIS geoinformation software has been used in order to analyze the spatial distribution of solar radiation in the Hernád Valley. In this case, the required input parameters have been determined using data measured there.

Changes in the global radiation are determined mainly by the geographical latitude. The other affecting factor is the air circulation having impact via cloudiness, amount of sunny hours and last but not least via transparency of the atmosphere (different air masses). Orography can also strongly modify the spatial and temporal pattern of global radiation. GIS programs are able to handle the surface characteristics with very high accuracy, but their weakness is that the meteorological conditions (cloudiness, water vapor content, etc.) are integrated indirectly using parameterizations (see Section 2.2).

Evaluation of global radiation data provides essential information for planning and economic analyses of solar energy utilization projects in the Hernád Valley. Examinations can be carried out for any point of the region by combination of statistical analyses and geoinformation methods.

2.1. Diurnal and annual courses of global radiation

Diurnal and annual courses of global radiation have been examined using the one-year-long dataset of the weather station of the airport of Kosice, located 25 km north from the settlement of Hidasnémeti. The raw database covers the period between May 2009 and April 2010, the hourly global radiation data are given in J/cm^2 (1 J/cm^2 = 2.778 W/m^2 hour). In the followings, the unit of W/m^2 will be used. Global radiation has a nearly symmetric curve with a maximum in June-July during the year. The curve reaches its minimum in the winter period in December, when the maximum is 367 W/m^2. There are higher maximal values in January and February, with 392 W/m^2 and 483 W/m^2, respectively. Values increase gradually in the spring reaching 714 W/m^2 in March and even 900 W/m^2 in May. There is a gradual decrease in the autumn months, although values are a bit lower than in the spring: 739 W/m^2 in September, while 422 W/m^2 in November. Highest values of global radiation occur in the afternoon, in the summer months with maxima over 800 W/m^2 and average over 435 W/m^2 between 9 and 15 UTC. Annual course of global radiation has reached its maximum in July with 933 W/m^2 during the studied period.

Diurnal curves show a symmetric distribution also with a maximum at noon independently from the seasons. Only the amplitudes of the curves are different according to the seasons (*Fig. 2*). Minima occur in December with 143 W/m^2. Intensities reach 21 W/m^2 at 9 UTC in the morning and reach 64 W/m^2 by 15 UTC. Highest intensities occur at the summer solstice in June, when it reaches 609.3 W/m^2 at noon, 202.7 W/m^2 in the morning (6 UTC), and 109.7 W/m^2 and late afternoon (18 UTC).

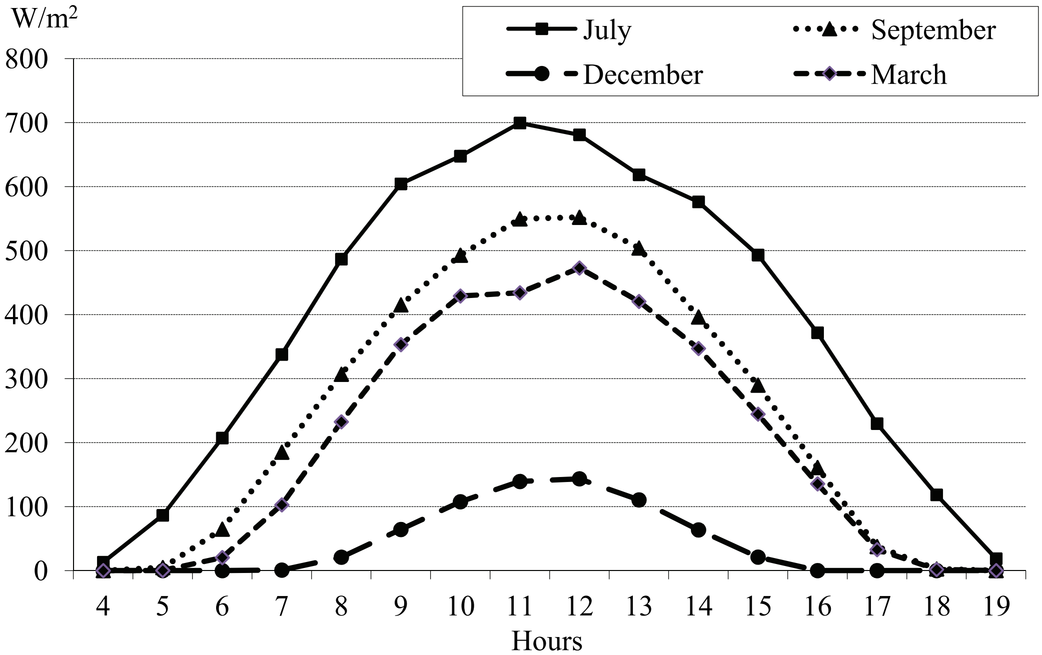

Fig. 2. Diurnal course of hourly average global radiation (W/m^2) at the weather station of Kosice during the 2009–2010 period.

Hourly values of global radiation are dependent on synoptic conditions which can change hour by hour significantly. Annual course of diurnal amounts of global radiation are presented in *Table 1*. It can be observed that values appear in 4 categories in the winter months, while they scatter in a much wider range in the summer period.

Table 1. Relative frequency of diurnal amounts of monthly global radiation (%) at the weather station of Kosice of the 2009–2010 period

W/m^2	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0–500	22.6	3.6								6.5	**53.3**	32.3
501–1100	**51.6**	39.3		3.3					3.3	**35.5**	26.7	**54.8**
1101–2200	25.8	**46.4**	16.1	10.0	3.2	6.7		6.5	6.7	29.0	13.3	12.9
2201–3300		10.7	29.0	16.7	6.5	6.7	3.2	6.5	10.0	19.4	6.7	
3301–4400			**48.4**	23.3	3.2	16.7	12.9	19.4	**40.0**	9.7		
4401–5500			6.5	10.0	19.4	13.3	16.1	22.6	33.3			
5501–6600				**26.7**	29.0	**26.7**	16.1	**38.7**	6.7			
6601–7700				10.0	**32.3**	16.7	**38.7**	6.5				
7701–8800					6.5	13.3	12.9					

2.2. Examination of the spatial pattern of global radiation

On the base of point-like measurement data, high resolution radiation maps of the region have been elaborated using geoinformatic tools (Esri ArcGIS Solar radiation module). As the global radiation is determined by many factors, the module contains various setting options. One of the most important factors is the aspect and slope derived from the characteristics of the surface. This kind of information can be obtained from the input digital elevation model (DEM). The program recognizes the geographical latitude of the area even at the moment of loading the DEM, furthermore, the inclination angle of solar radiation can also be determined. The next step contains the time settings. The most important parameter is the sequence of the day in the given year. Based on this parameter, the inclination angel of the radiation, the way length of solar beam in the atmosphere, and the astronomical duration of sunshine can be determined. All these parameters of radiation presented above can be calculated exactly. In the following step, the input parameters refer to the atmospheric conditions like cloud cover, humidity, opacity, etc. Regarding these parameters in the module two, values can be adjusted, namely the proportion of diffuse radiation and the transmissivity of the atmosphere (τ). The values of proportion of diffuse radiation was taken from the PVGIS dataset (*http://re.jrc.ec.europa.eu*). The parameterization of transmissivity is elaborated based on measured global radiation values. The monthly radiation values are classified in function of standard deviation (σ) into three categories, namely $M \pm \sigma$ interval concerning situations with average radiation values, $M+2\sigma$ for situation with high values, and $M-2\sigma$ interval including the situation of low global radiation. In order to determine a monthly τ parameter, an approximate τ was determined for each category weighted with the number of cases of the given category. In this way, an empirical τ parameter was calculated separately for each month (*Bartók et al.,* 2011).

Introducing the DEM of the region, the proportion of diffuse radiation, and the empirical τ parameter into the GIS Solar radiation module, high resolution global radiation maps were elaborated for different periods. Results regarding the period of May-August (warmest four months of the year) are presented in *Fig. 3*. Statistics of global radiation income (sum) of the region for the period between May and August are the following. The average is 501 kW/m^2, the minimum is 438 kW/m^2, the maximum is 563 kW/m^2, and the empiric standard deviation is 11 kW/m^2, respectively. The high resolution of the map makes it possible to evaluate radiation conditions of slopes of different expositions.

Evaluation of data of incoming global radiation provides essential information for planning and economic analyses of solar energy utilization projects planned in the Hernád Valley. Examinations like presented above can be carried out for any point of the region, where utilization of solar energy takes place by combination of statistical analyses and geoinformation methods. It is reasonable, since local features, especially orography, can modify the spatial and temporal pattern of global radiation remarkably.

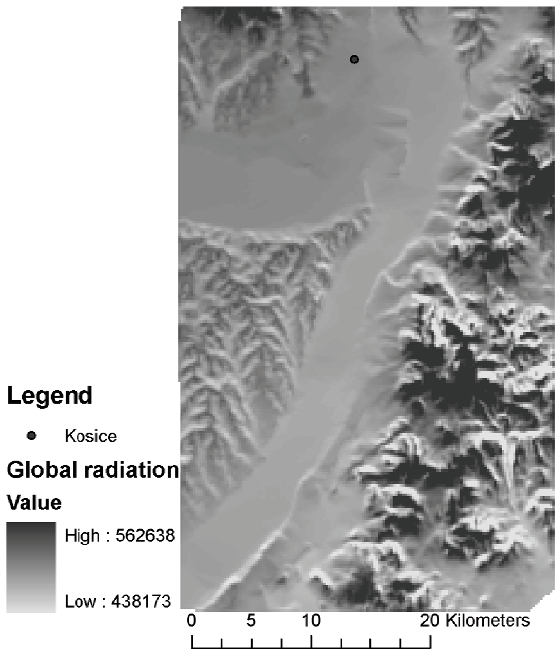

Fig. 3. Total global radiation (W/m^2) in the Hernád Valley for the period between May and August.

3. Determination of wind energy potential in the Hernád Valley

Besides the wind climatological research, other important aim of the research program was to describe the spatial characteristics of the wind energy potential related to orography in the Hernád Valley.

The data logger mounted on the measurement mast carried out measurements in every 10 seconds and calculated averages for 10-minute intervals. Resolution of the anemometer was 0.1 m/s, while wind directions have been recorded with a resolution of 1°. Measurements lasted from April 23, 2010 to April 27, 2012 with a time span of 24 month on the whole. Datasets had been tested before the statistical analyses and modeling. Time series have proved to be discontinuous due to rigorous weather conditions in the winter months. There have been lacks of data in December – February in the winter of 2010–2011, and once in July 2010. Lacks of data have not been complemented by statistical methods. This way we have gained wind data for 67% of the studied period.

3.1. Diurnal courses of different statistical parameters of wind speeds

Daily courses by 10-minute intervals of the average wind speeds, its standard deviation, variation coefficient, and the parameter in the Hellmann's wind profile (Eq. (1)) for the 525 days represented with wind measurement data of the before mentioned measurement period have been calculated for both heights. Mean diurnal course of wind speeds are presented in *Fig. 4*. Its maximum occurs between 13 and 15 UTC at both heights, while minima occur before dawn (3–4 UTC), what is in accordance with the basic characteristics of the wind climate of Hungary. Diurnal fluctuation is 1.6 m/s at 10 meters and 1.4 m/s at 20 meters, what refers to less changeable nature wind speeds of the higher level. Differences in the averages of the two levels do not exceed 0.4 m/s, with smaller differences in the day. Averages for the whole period are 3.2 and 3.4 m/s, respectively. Diurnal courses of variation coefficients (standard deviation/ average) are presented in *Fig. 5*. According to this, variability decreases in the day, especially at 10 meters.

Measurements carried out at two heights makes the determination of the α parameter possible in the equation of Hellmann:

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

where v_1 stands for the wind speed measured at height h_1, while v_2 is the wind speed at height h_2. The actual value of parameter α is a function of the roughness of the surface and the equilibrium conditions of the air near the surface mainly. Due to the latter one it is temperature-dependent, therefore, it has a diurnal and seasonal course. Using α, wind speeds at higher levels can be estimated on the base of wind speeds measured at a given height.

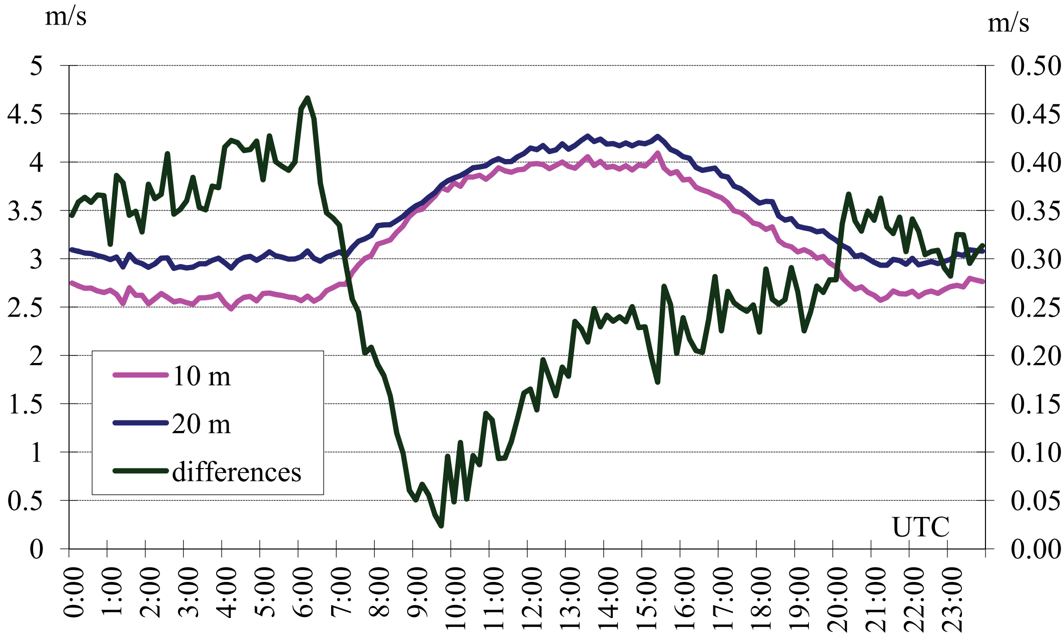

Fig. 4. 10-minute diurnal course of the average wind speeds and their differences.

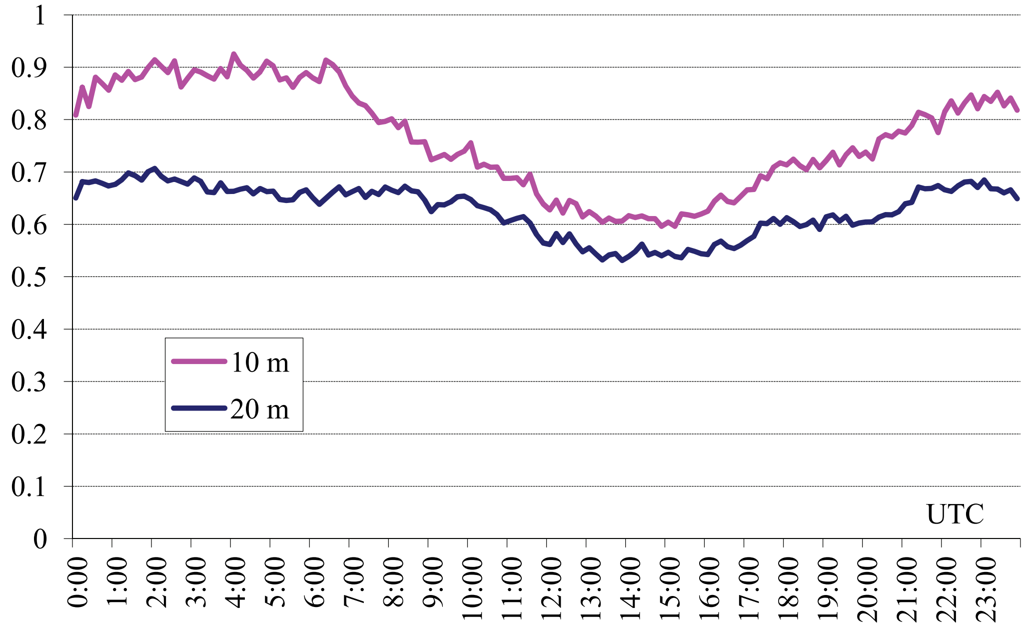

Fig. 5. 10-minute diurnal course of the variation coefficient of wind speeds.

„Momentary” values of parameter α have been calculated from 10-minute wind speed averages at 10 and 20 meters using Eq. (1) for each day first, then averages for the points of time have been calculated. Diurnal course of parameter α follows the diurnal course of differences in hourly average wind speeds between the 10 and 20 meters levels, namely its value is raised between 4 and 6 in the dawn. Its average is 0.22, what is close to the value (0.25) proposed for calculations for the whole country (*Dobi* and *Mika*, 2007).

As it was mentioned before, α is temperature dependent via equilibrium conditions of the atmosphere. It means that low temperatures near the ground (atmospheric stability) leads to high values of α, while high temperatures close to the surface (atmospheric instability) cause low values of α (*Radics*, 2003). Its values are higher in the night according to other studies also (*Tar*, 2004, 2007), but its diurnal case is more regular than in our case: it can be considered as constant with a fluctuation of ±0.05 from 21 to 6 UTC, while it decreases from 6 to 12–13 UTC and starts increasing later in the day. Fig. 6 shows a different diurnal course which could not be explained yet. It might be caused by the effect of orography or asymmetry of our data base (less winter days), or even data error cannot be excluded. To solve the problem, further examinations are required into this issue.

More regular diurnal course can be approached using hourly averages of the parameter. In such case, hourly average wind speeds for 10 and 20 meters have to be determined. After that, hourly average wind speeds for higher levels can be calculated with a better chance by Eq. (1). Diurnal course of hourly averages of wind speeds at heights of 20, 40, 60, and 80 meters have been calculated from 10-meter averages using the hourly values of the parameter. Results are presented in *Fig. 5* as well.

Comparison of values measured at 20 meters and values calculated for that height by the before mentioned method provide some information about the error of the Hellmann model. It can be seen that calculated values are higher by 0.1–0.4 m/s in each hour (0.2 m/s on average), what is 6.2% of the diurnal mean value (3.2 m/s). Higher differences occur between 1 and 7 UTC.

According to other authors and our previous examinations carried out in different parts of Hungary (*Kircsi* and *Tar*, 2008; *Tar*, 2009), there is a change in the average diurnal course of wind speeds at a height between 60 and 80 meters. Diurnal course is similar to that presented in *Fig. 4* at lower heights: it has a strong maximum at 13–14 UTC and a minimum in the night. At the same time there is an expressed minimum over that level in the early afternoon. Consequently, there have to be a so-called inflexion height, where diurnal course of (average) wind speeds is random. This hypothesis has been justified by statistical analyses. The inflexion height can be found at 50 meters at the weather stations examined so far (*Tar,* 2009). Unfortunately, inflexion height cannot be identified in *Fig. 6*. The reason for this requires further studies as well.

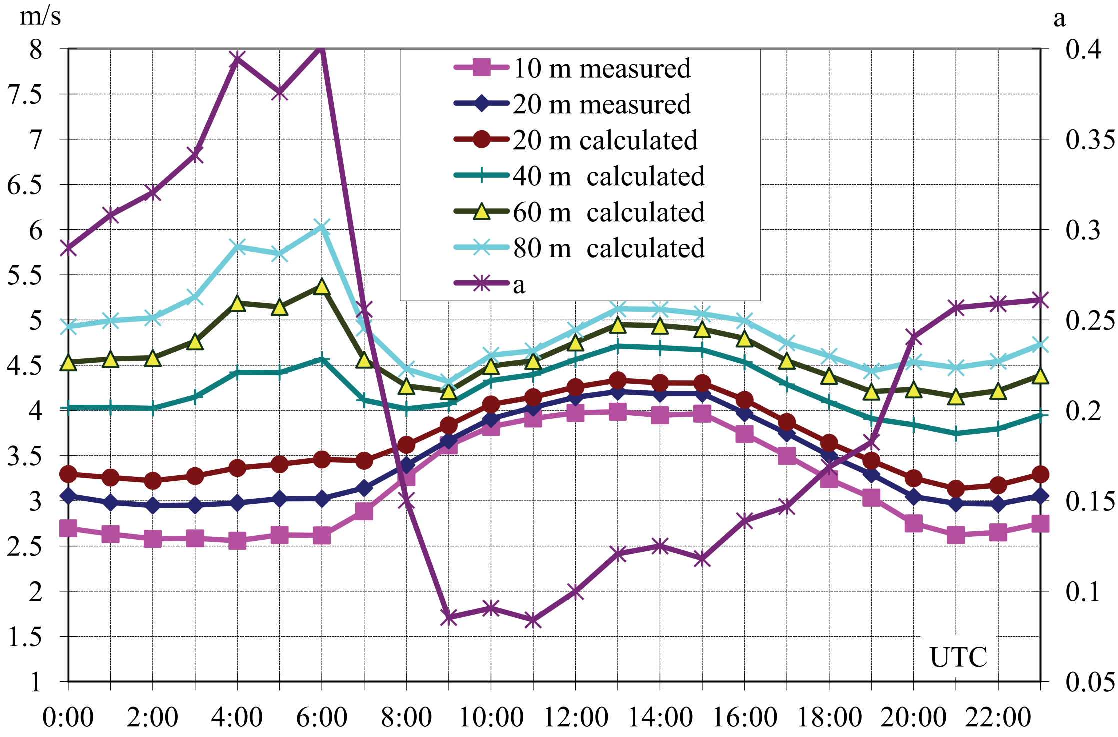

Fig. 6. Hourly average diurnal courses of the wind speeds measured and calculated for different heights and average diurnal course of the Hellmann exponent (α).

3.2. Examination of the spatial pattern of wind speeds

Speed of the air flowing over a solid surface is effected by internal and external friction, orography roughness of the surface, and artificial surface obstacles among other forces. In the case of regions with complex surface, models based on CFD analyses are used in engineering most frequently for revealing spatial patterns of wind speeds.

For wind potential survey of the Hernád Valley, the EV version of WindSim 5.1 software developed by the Norwegian VECTOR AS has been used. It is a wind farm planning tool based on computational fluid dynamic (CFD) simulations of wind flows over complex terrain. The core of the software pack is the PHOENICS software, which finite volume code based on solving the incompressible Reynolds-averaged Navier-Stokes equations (RANS) together with a two-equation turbulence model (k-epsilon turbulence model) (*Castro et al.,* 2003*; Lopez et al.,* 2007). This method favored due to their robustness and low computational costs.

The Reynolds averaged Navier-Stokes equations are used to simulate the turbulent flow field in the following way:

– continuity ($i = 1,2,3$):

$$\frac{\partial (u_i)}{\partial x_i} = 0. \tag{2}$$

– Reynolds-averaged Navier-Stokes equation ($i = 1,2,3$):

$$\rho\left(\frac{\partial \overline{u_i}}{\partial t} + \overline{u_j}\frac{\partial \overline{u_i}}{\partial x_j}\right) = -\frac{\partial \overline{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\mu\left(\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i}\right) - \frac{\partial \rho \overline{u_i' u_j'}}{\partial x_j}, \tag{3}$$

where u_i represents the velocity component, ρ is the density, p is the pressure, μ is the dynamic viscosity, and t is the time.

The software approaches the nonlinear dynamic equations describing mass-, momentum-, and energy transport by iteration.

The model has a modular structure and it approaches the spatial distribution of average wind speeds influenced by orography in several steps determining the prospective energy production of the chosen wind energy utilizing instruments practically.

The base of the running of the WindSim model is a digital terrain model. The digital terrain model used in our research has been derived from the SRTM (Shuttle Radar Topography Mission) database. It has been completed by an international consortium led by NGA (National Geospatial-Intelligence Agency) and NASA in February 2000 (*Farr et al.,* 2007). Elevation datasets of the SRTM database contain buildings, forests, and other roughness elements besides orography. For this reason, a roughness height homogeneous in space was given for the running of WindSim model. Roughness increasing effects of surface cover has not been considered in any other forms.

Before the wind climatological examinations, it had been presumable that the valley of the river has a strong effect on air movements in the study area. Northern-northeastern and the opposite southern-southeastern wind directions are the most frequent in the upper part of the Hernád Valley near the Hungarian-Slovakian border. Highest wind energy content belongs to these directions as well; therefore, they are the most important for establishment of wind energy utilization in the region. Turbulence intensity calculated on the base of standard deviation of wind speeds reaches its maximum when winds blow from the 135° SE and 270° W wind direction sectors.

Windenergy potential maps of the Hernád Valley have been generated using WindSim model for 3 heights above the surface (50, 80, and 110 meters). The numeric model has run with a grid number limited in space. The model area expands to 40 km N, E, S, and W from the measurement mast, so it spreads into the Slovakian part of the Hernád Valley. All orographic elements that have an impact on air movements have been taken into consideration from the Eperjes-

Tokaj Mountains on the east side, the ridges over 1,000 meters of the Slovak Ore Mountains in the northwest, the basin of Kosice and the Hernád Valley (*Kircsi,* 2011; *Bíróné Kircsi et al.,* 2011).

Verification of the result maps has not been carried out yet, estimations are not justified, but they can already be used for identification of areas suitable for wind energy utilization.

On the base of spatial distribution of wind speeds of the height of 50 meters it is visible (*Fig. 7a*) that the low laying basin of Kosice and the Hungarian section of the Hernád Valley is in wind shadow, so it is moderately windy. Annual average wind speeds exceed 5 m/s in the region of highest mountain ridges only. Irrespectively of this, the lower part of the Hernád Valley south of the settlement of Encs and the western side of the valley rising toward the Cserehát hills seems to be suitable for wind energy utilization. Highest wind speeds can be found over the peaks near Hejce and Vilmány.

Wind maps generated for heights of 80 and 110 meters are quite similar (*Figs. 7b* and *7c*), however, wind speed averages have not increased remarkably parallel with the height. The Hernád Valley is not the windiest region of Hungary, anyway. Wind potential in the study area makes possible to establish wind turbines with an axis height of about 100 meters at least.

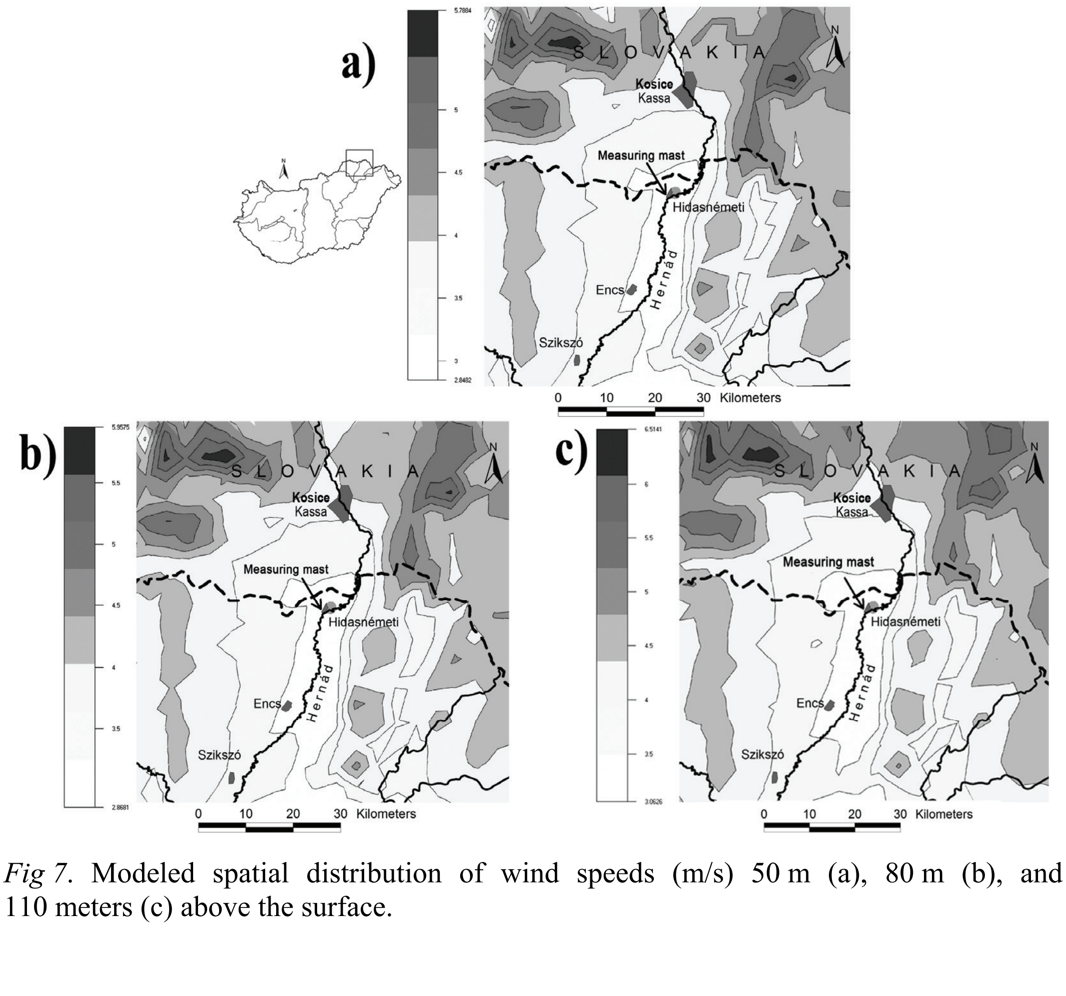

Fig 7. Modeled spatial distribution of wind speeds (m/s) 50 m (a), 80 m (b), and 110 meters (c) above the surface.

3.3. *Relationships between the diurnal average wind speeds of Kosice and Hidasnémeti*

Diurnal average wind speed data of the airport of Kosice for the studied period can be found at *http://ncdc.noaa.gov/oa/ncdc.html*, so they can be compared to our data measured at Hidasnémeti. It is a question anyway whether they are accurate or not. Accuracy of the wind speed datasets available at the homepage have been tested by comparison of base statistics of them and the purchased dataset. Our examinations have proved that they are data from the same weather station (*Tar,* 2012).

Diurnal average wind speed datasets of Kosice have been downloaded from the before mentioned homepage for the period between April 1, 2010 and October 31, 2011, what means 579 days. Our measurements cover 525 days, data for 54 days is missing. An attempt has been made to complete the diurnal average wind speed database by regression for both heights. *Figs. 8* and *9* show the relationships between the datasets available for both stations (525 days) with the two trend lines that fits best (they have the highest correlation index). Unfortunately, there is not any information on the height of the anemometer at the weather station of Kosice, but it is not important from the aspect of regression analyses. Linear trend has been selected for further analyses due to values of correlation index (R^2). T-test has showed that linear correlation coefficients differ significantly from 0. The significant correlation coefficients enable the generation of diurnal mean wind speeds to Hidasnémeti from data of Kosice with the help of regression equations without measurements.

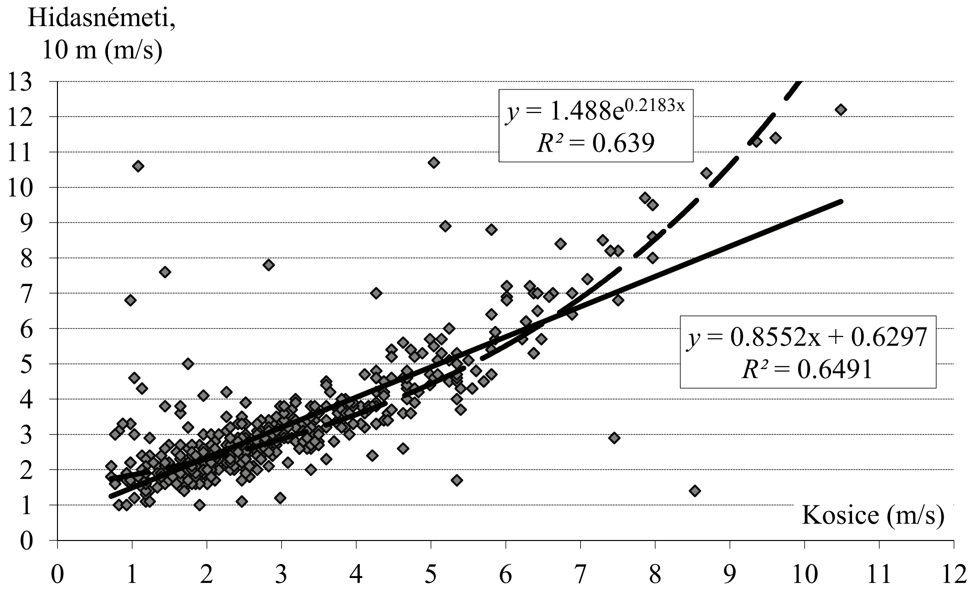

Fig. 8. Regression between datasets of diurnal average wind speeds of Kosice and Hidasnémeti at the height of 10 meters.

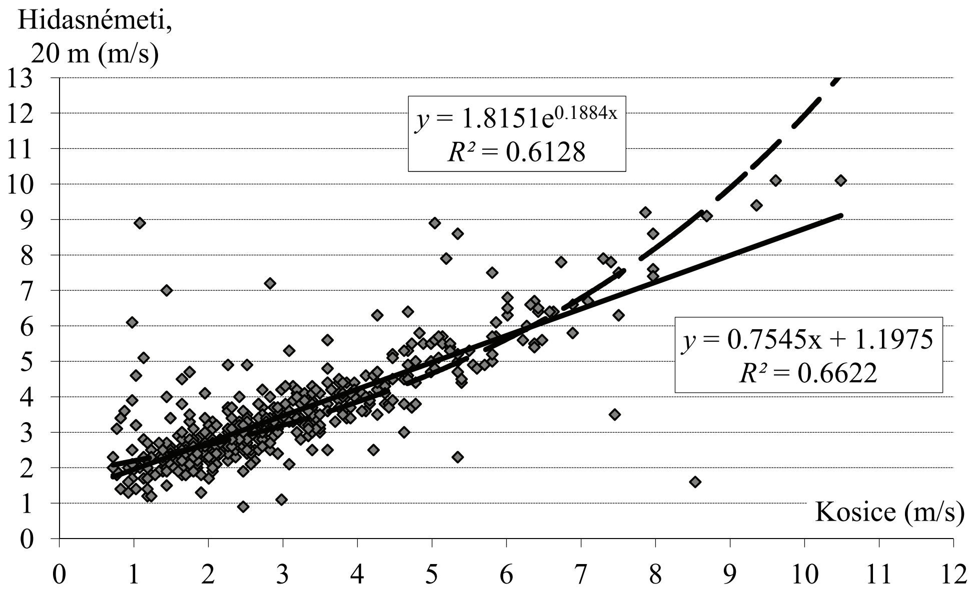

Fig. 9. Regression between datasets of diurnal average wind speeds of Kosice and Hidasnémeti at the height of 20 meters.

As a first step, datasets for 10 and 20 meters of Hidasnémeti have been reconstructed using regression equations $y = 0.8552x + 0.6297$ and $y = 0.7545x + 1.1975$ (where x stands for datasets of Kosice), in order to determine the error of the regression model. Mean relative error at 10 meters is 6.6%, standard deviation is rather high (33.3%), therefore variation coefficient is also high (5.04). Mean relative error at 20 meters is 5.7%, standard deviation is 30%, and variation coefficient is 5.27. Mean relative error is positive in 63.8% and 59.2% of all cases at 10 and 20 meters, what means that the model overestimates.

The most important statistical characteristics of the measured and estimated diurnal average wind speeds are given in *Table 2*. Variability (standard deviation, variation coefficient) of estimated, modeled values is lower than that of measured ones. Values of extremities like range have changed: the latter one has decreased from 11.2 to 8.4 at 10 meters and from 9.2 to 7.4 at 20 meters. Values of skewness and kurtosis show that modeled datasets are more regular, as it can be seen in *Fig. 10*.

The modus of the measured and estimated data falls into the 2–3 m/s interval at both heights according to *Fig. 10*. There is a higher frequency of occurrence by 3 and 2 % in the case of estimated data. It is visible as well, that frequency of values lower than the modus decreases at both heights, while frequency of values higher than the modus increases up to about the 6-7m/s interval together with the change of the coefficient of skewness (*Table 2*). However, homogeneity (χ^2) tests (*Vince,* 1975) have proved that measured and estimated values belong to the same distribution at both heights at a level of 99%.

More detailed results on the wind climatology of the study area can be found in *Tar* (2011a, b) and *Tar et al.* (2011).

Table 2. The most important statistical characteristics of the measured and estimated by regression diurnal average wind speeds at Hidasnémeti

	10 m		**20 m**	
	measured	**estimated**	**measured**	**estimated**
average	3.2	3.2	3.4	3.4
standard deviation.	1.71	1.38	1.49	1.22
coefficient of variation	0.54	0.44	0.44	0.35
minimum	1.0	1.2	0.9	1.7
maximum	12.2	9.6	10.1	9.1
lower quartile	2.1	2.2	2.4	2.6
median	2.7	2.8	3.0	3.1
upper quartile	3.6	3.8	4.0	4.0
skewness	2.20	1.42	1.63	1.42
kurtosis	6.03	2.30	3.29	2.30

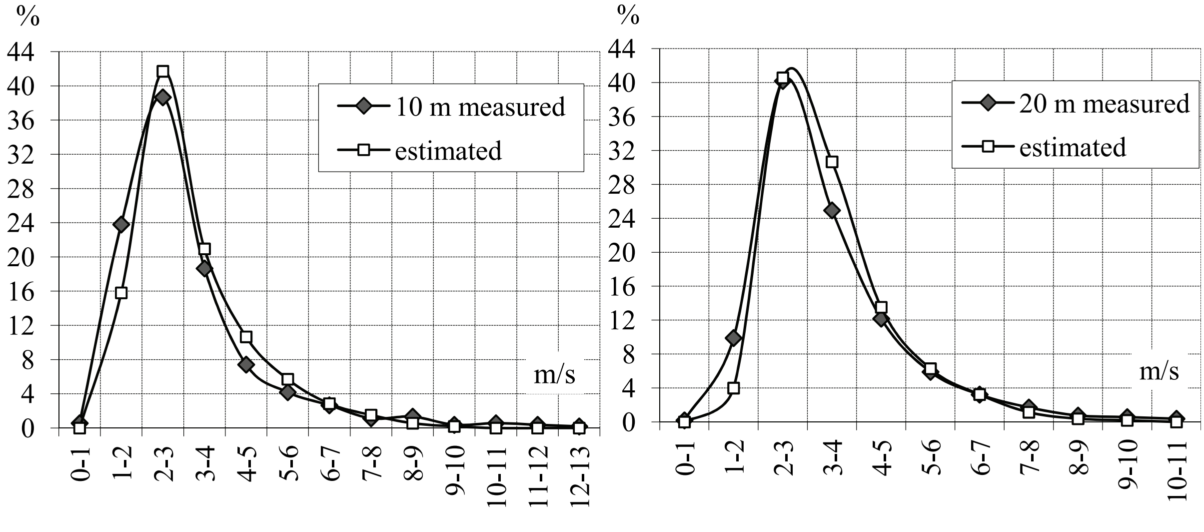

Fig. 10. Distribution of measured and estimated values of diurnal average wind speeds at 10 and 20 m heights at Hidasnémeti.

4. Supplementary investigations (biomass, social aspects)

The local support and biomass potential in the Hernád Valley were also examinated, because they are essentials for the future establishment of the renewables in the area. Results of an own questionnaire attitude survey show that more than 80% of citizens (1,188 persons) questioned in 21 of the total 30 settlements have heard about wind and solar energy. Majority of citizens interviewed consider wind turbines, low capacity wind generators, and solar panels as acceptable, morally supportable, and realizable. However, only 10 % of citizens interviewed would tolerate a biomass burning power plant or a small heat generating power plant in their own settlement (*Tóth*, 2011; *Tóth* et al. 2012). Based on the estimations for biomass potential, about 125,000 tons of wood and herb biomass suitable for energy production is being produced annually in the study area after satisfying raw material and other demands. The estimated value of that mass is 4.4 billion forints, while bioenergy end products cost 7.8–8.6 billion forints. Approximately 75% of it remains in the region (*Bai*, 2012). All of these shows that not only solar and wind energy but bioenergy potential has also great importance in the Hernád Valley, but attitude of local inhabitants for bioenergy is not as positive as for the sun- and wind energy. Details of these results have already been published in another article.

5. Discussion

Solar energy potential of the Hernád Valley has been evaluated in the course of our examinations on the base of measured data by GIS tools. It can be stated that the region have significant solar energy potential with a total solar radiation income of 1204.8 kWh/m^2 measured at the weather station of Kosice during the studied period, what can be even higher in areas of advantageous exposition. This endowment can serve as a good base for further development of solar energy utilization in the region. Solar energy can be introduced in some new fields like ecologic and silvicultural applications.

Northerly and the opposite southerly winds are the most frequent in the upper part of the Hernád Valley near the Hungarian-Slovakian border. Highest wind speeds belong to northern-northeastern and southern-southeastern directions. Turbulence intensity calculated on the base of standard deviation of wind speeds reaches its maximum when winds blow from the southeastern and western wind directions. Wind energy potential maps of the Hernád Valley have been generated for heights of 50, 80, and 110 meters show that the Hungarian section of the Hernád Valley lays in wind shadow of the bordering mountain ridges. In the case of the model, the annual mean wind speeds weighted by wind direction distribution reach 2.8–3 m/s and 3.5–4 m/s in the northern and southern part of the Hungarian section of the Hernád Valley at heights of 50 and 110 meters. Energy content of air flows is low (nearly 60 W/m^2) at 50 meters. However, the lower part of the Hernád Valley, south of the settlement of Encs and the western side of the valley rising toward the Cserehát hills seem to be suitable for wind energy utilization. Highest wind speeds can be found over the ridges over 1,000 meters bordering the basin of Kosice and the peaks in the Eperjes-Tokaj Mountains on the east side of the valley.

On the base of wind measurements carried out in Hidasnémeti between April 23, 2010 and April 27, 2012 it can be stated, that wind potential of the year 2011 was far behind the Hungarian annual average. It has been found that the software pack used for the spatial extrapolation of wind speeds is suitable for surveying wind energy potential of the Hernád Valley and its broader environment, and for fulfilling the tasks of the project (*Bíróné Kircsi* and *Vass*, 2011). Our examinations have showed that in spite of temporal fluctuations, utilization of wind energy in the study area can be expedient and effective, especially in the case of application of low starting speed wind turbines.

Not only solar and wind energy but bioenergy potential has also great importance in the Hernád Valley but the attitude of local inhabitants for bioenergy is not as positive as for the sun- and wind energy.

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