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Assessment of the long-term wind energy resources in the Southern Bârlad Plateau. An applied climatology study

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Abstract

In order to evaluate the long-term wind conditions and energy resources in the Southern Bârlad Plateau, the WINDATLAS method has been applied, using the numerical software programs WindPRO 2.7 and WAsP 9. For this purpose, 2 years (2008 – 2010) of in-situ wind measurement data from two locations were used. These time series have been adjusted to a 30-year long-term period (1981-2010), using NCAR global weather analyses data, and validated with the monthly means of the wind speed recorded at Galați meteorological station (1981-2010). On the basis of the new generated long-term time series, local wind statistics have been obtained, which were used for wind conditions assessment and energy yield calculations within the study area. The average wind speed, the Weibull parameters for the vertical wind profile, as well as the expected wind energy resources have been determined. The Southern Bârlad Plateau is characterized by high wind energy potential demonstrated by long-term averaged wind speeds larger than 7 m/s (at 120 m a.g.l.), similar to Dobrogea region, and by corresponding wind energy values of more than 3000 kWh/m^2 at hill top positions. Another key issue is that the energy potential of this area is relatively constant at multi-annual scale, with prevailing winds from northern and southern directions, making it highly suitable for the development of Multi-Megawatt wind farms. The results obtained by applying this complex methodology can be practically valorized by being further integrated in energy production estimates and feasibility studies for wind farms.

Keywords: *WINDATLAS method, Weibull distribution, long-term wind statistics, energy yield.*

Rezumat. Evaluarea potențialului eolian din sudul Podișului Bârladului. Studiu de climatologie aplicată.
În vederea evaluării potențialului eolian în sudul Podișului Bârladului, am aplicat metoda WINDATLAS, cu ajutorul softurilor numerice WindPRO 2.7 și WasP 9. În acest sens, am utilizat 2 ani (2008 – 2010) de măsurători de vânt in-situ în două locații din acest areal. Aceste măsurători au fost ajustate, pentru a avea valabilitate multi-anuală, cu ajutorul setului de date NCAR, curpinzând 30 ani (1981 – 2010) de modelări climatice globale, și au fost validate cu ajutorul valorilor de viteză medie lunară a vântului măsurate la stația meteorologică Galați între 1981 și 2010. Pe baza noilor serii de date astfel generate, au fost obținute statistici locale ale vântului, care au fost apoi utilizate pentru evaluarea potențialului eolian și pentru calculațiile energetice în cadrul ariei de studiu. Au fost determinate astfel viteza medie a vântului, parametrii distribuției Weibull ai profilului vertical al vântului și resursele energetice potențiale. Sudul Podișului Bârladului se caracterizează printrun potențial energetic eolian ridicat, manifestat prin viteze medii multi-anuale ale vântului de peste 7 m/s (la înălțimea de 120 m), similare cu cele întâlnite în Dobrogea, și prin valori corespondente ale energiei vântului de peste 3000 kWh/m^2 la aceeași înălțime pe culmile dealurilor. O altă constatare foarte importantă este faptul că potențialul eolian în cadrul locației este relativ constant la scară multi-anuală, cu vânturi dominante din sectoarele nordic și sudic, ceea ce face ca această zonă să fie optimă pentru dezvoltarea parcurilor eoliene cu turbine multi-megawatt. Rezultatele obținute prin aplicarea acestei metodologii complexe pot fi valorificate în mod practic prin integrarea lor în estimări ale productibilului energetic electric și în studii de fezabilitate pentru parcurile eoliene.

Cuvinte-cheie: *metoda WINDATLAS, distribuția Weibull, statistică eoliană, calcul energetic.*

Introduction

Romania is considered to have the highest wind energy potential in the South-East Europe and the second one in Europe, with a predicted total installed capacity of 14000 MWh (Mihailescu, 2009). In the last decade, following the EU community regulations regarding the increase of renewable energy sources share in the total energy consumption (Colesca and Ciocoiu, 2013), there was a continuous demand for good quality in-situ high-frequency wind measurement data and wind energy potential studies for extensive areas, especially in Dobrogea and Southern Moldavia.

The use of wind speed and direction data measured at 10 m a.g.l. at meteorological stations across Romania was no longer sufficient as the wind energy assessment studies and energy production reports for wind farms required values measured and modelled for hub heights of the wind turbines, usually higher than 50 m a.g.l. Hence, the need for a re-evaluation of Romania's wind energy potential. In this context, there are some recent studies (Vespremeanu-Stroe and Tătui, 2011; Vespremeanu-Stroe et al., 2012) and maps (produced, among others, by the Romanian Administration of Meteorology and Wind Power Energy or MegaJoule private companies) which present the wind regime of Romania, its energetic potential or climate variability influences.

Long-term wind energy assessment methods and approaches (e.g. Carta et al., 2013; Weekes and Tomlin, 2014) were extensively discussed and wind energy potential studies (e.g. Bataineh and Dalalah, 2013; Nawri et al., 2014) were presented in the international literature. In Romania, the wind energy potential studies were performed especially by private company consultants and, therefore, we can observe a lack of scientific studies regarding the methodology, approaches and results of such wind energy assessment research. In this context, we aim at quantifying the wind energy resources in the Southern Bârlad Plateau through generation of detailed wind speed and energy maps in order to validate the implementation of wind farms in this area. Because of the complex computational resources needed and the lack of reliable data for such a large area, we are describing in this applied climatology study the methodological approach only for a study case representative for the wind conditions of the entire plateau.

Study area

The study site is located in the eastern part of Romania, within the Covurlui High Plain (the southernmost unit of Bârlad Plateau), 23 km N-NW of Galați city and about 40 km SE of the town of Tecuci (Figure 1). It covers the flat top areas of a monoclinal plateau which tilts down gently southward, at altitudes between 98 and 172 m a.s.l. The surrounding relief energy and density of fluvial fragmentation are very low due to both pluvial and hydrological regime and to the general morphology which is specific to high plains and low plateaus. The general aspect is plane or rounded and, with some exceptions located in the nearby valleys` versants, where inclinations could rise up to 20°, the slopes are between 0° and 8° for the majority of surfaces. The terrain conditions of the surrounding area are characterized by a wavy relief which is not very accentuated, with several well-rounded ridges running from North to South. The height difference between hill tops and the separating valley structures amounts to app. 60 m. With regard to the closer vicinity of the study area, the landscape gradually decreases gently towards eastern and southern directions and steeply northward and westward. Similar terrain appearance can be observed in the far field (15 km distance) towards the North, West and SW, while the altitudes are slightly decreasing to the South.

From the climatic point of view, the Southern Bârlad Plateau is located in a transitional area between the Eastern Europe continental climate and the Balkan Peninsula pre-Mediterranean temperate climate. These particular climatic characteristics are represented by an excessive continental climate, with high temperature amplitudes, low precipitation values (~500 mm in the study area), hot and dry summers and cold winters with strong winds (Climate of Romania, 2008).

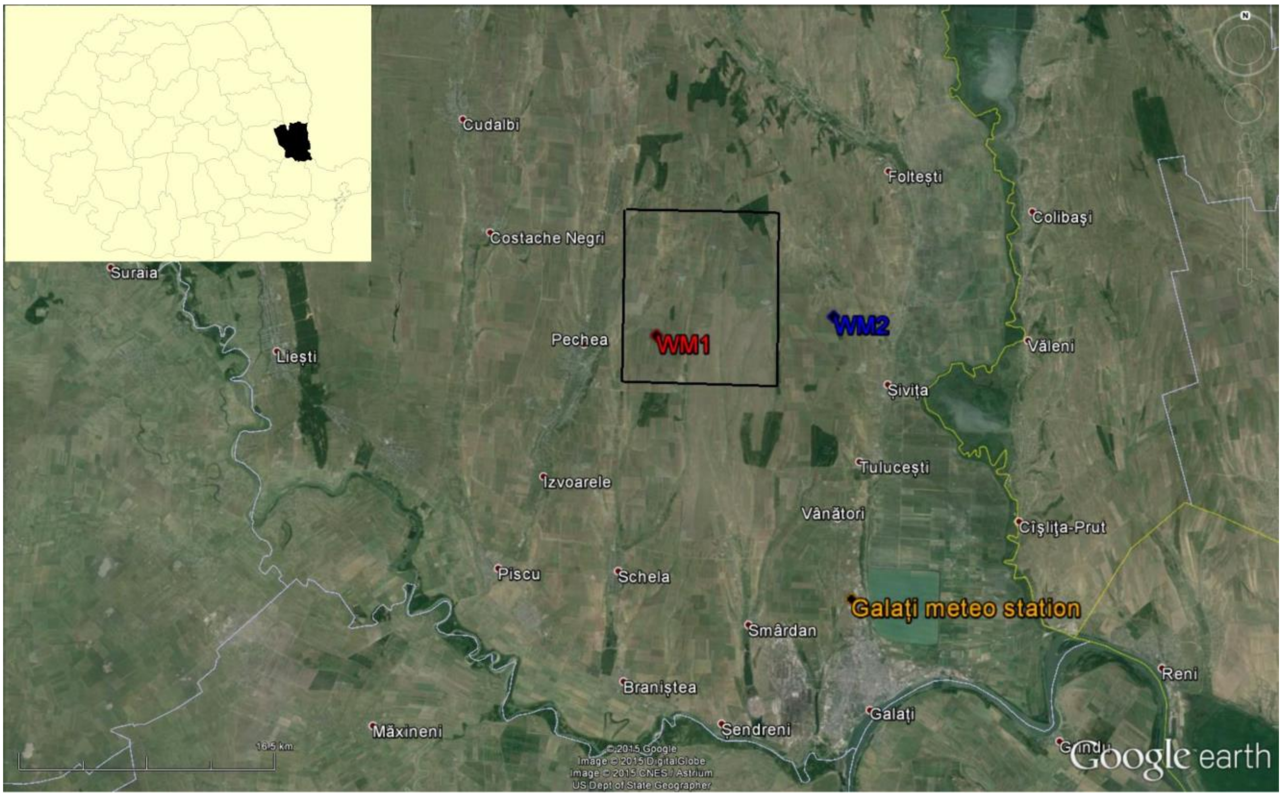

Fig. 1 Locations of the study site (*black rectangle*), of the wind measurement sites (WM1 and WM2) and of the meteorological station at Galați in the frame of the Galați County, Romania.

The plateau is delimited by the 10°C annual isothermal line (10.5°C is the multi-annual average temperature measured at Galați meteo station between 1961 and 1990). The annual mean temperature in the study area is approximately 11°C (12.6°C were measured between November 2008 and November 2009). The annual mean air pressure in the study area oscillates between 980 and 1000 hPa (the multi-annual average at Galaţi is 1008.2 hPa). The annual average air humidity is 76-78%.

The multi-annual mean wind speed measured at Galați meteo station between 1961 and 2003, at 10 m height, is 4.26 m/s (Vespremeanu-Stroe and Tătui, 2011). The annual average number of days with wind speeds higher than 16 m/s is between 25 and 50 days (1961 – 2000). In terms of wind direction, the highest frequency is registered by the northern sector winds (23.8%).

Data & Methods

In order to evaluate the average wind conditions in the frame of the study site, we used in situ wind measurements during 24 months (November 2008 – November 2010) from WM1 mast and from a mast situated at 11.7 km E-NE of the study area (WM2), with total heights of 50 and 60 m respectively (Figure 1). Measured data have been registered with equipment provided by NRG Systems with a sampling rate of 1 Hz as 10 min. averages for wind speed and wind direction. The position and configuration of each mast is presented in Table 1. All sensors have been calibrated according to MEASNET standards in advance of operation and functioned in good conditions.

Table 1: Location and measurement equipment presentation for WM1 and WM2 masts.

Site			**WM1**	**WM2**
Height a.s.l. (m)			130	155
UTM WGS 84 [m], Zone 35			E: 567130 / N: 5054254	E: 578803 / N: 5055894
Measurement period			2008-11-30 until 2010-11-08	2008-11-30 until 2010-11-08
Parameter	**Height**	**Sensor**		
Wind speed	60 m	NRG #40	-	Boom length: 155 mm Orientation: 0° (N)
Wind speed	60 m	NRG #40	-	Boom length: 155 mm Orientation: 157°
Wind speed	50 m	NRG #40	Boom length: 250 cm Orientation: 90° (E)	Boom length: 157 mm Orientation: 0°
Wind speed	50 m	NRG #40	Boom length: 250 cm Orientation: 270° (W)	
Wind speed	40 m	NRG #40	Boom length: 250 cm Orientation: 90°	Boom length: 157 mm Orientation: 0°
Wind speed	30 m	NRG #40	-	Boom length: 157 mm Orientation: 0°
Wind speed	20 m	Vector W200P	Boom length: 250 mm Orientation: 90° (E)	Boom length: 157 mm Orientation: 0°
Wind direction	60 m	NRG #200	-	Boom length: 157 mm Orientation: 170°
Wind direction	48 m	NRG #200	Boom length: 200 mm Orientation: 90° (E)	-
Wind direction	40 m	NRG #200	-	Boom length: 157 mm Orientation: 170°
Wind direction	20 m	NRG #200	Boom length: 200 mm Orientation: 270°	-
Temperature	3 / 10 m	NRG #110S	Boom length: integrated Orientation: 180°	Boom length: integrated Orientation: 0°
Pressure	3 m	NRG BP20	Boom length: integrated Orientation: 180°	-
Humidity	3 m	NRG RH5	Boom length: integrated Orientation: 180°	-

Long-term wind data being taken in the past and model calculations according to the WINDATLAS method by using WAsP (Petersen et al., 1981; Nielsen and Chun, 1994) conclude the approach. The long-term datasets consist in weather reanalyses data, provided by the U.S. American National Centre for Atmospheric Research (NCAR), and long-term observations at the Galați meteo station, provided by the NOAA National Climatic Data Center (NCDC). NCAR data are large-scale wind analyses, which cover the time period 1981-2010 (6-hourly values) for the study area (the center of the grid is 45.0°N / 27.5°E); they are based on two fixed heights of 10 and 42 m a.g.l. and are distance-weighted derived from the four nearest grid points of the calculation grid. These data are based on global numerical weather analyses and are characterized by a high temporal consistency contrary to local measurements. This dataset describes the large-scale wind field (scales ~250 km) and can be transferred to localized wind energy questions only if the smaller scale topographical and meteorological conditions aren't too complex. Data of the Galați meteorological station are covering a long-term period (1-hourly time series) of 50 years (January 1961 - December 2010) but, unfortunately, the data set shows a large number of gaps.

The calculation of the wind conditions is based on the planning software WindPro, version 2.7 (Nielsen and Chun, 2000) and the numerically flow model WAsP (Wind Atlas Analysis and Application Program), version 9. The WAsP model considers the influences of the parameters roughness, obstacles and orography on the wind conditions at defined points of reference according to the method of WINDATLAS. By using these as input parameters and by choosing suitable wind statistics based on representative wind measurements (normally long-term data), frequency of occurrence distributions of wind speed can be expressed as Weibull distributions and as functions of wind direction and height at a chosen point of reference.

The orography was assessed on an area of app. 1.600 km^2 (40 x 40 km) around the study site, based on various data (Shuttle Radar Topography Mission – SRTM and 1: 25.000 scale topographic maps), which were integrated in the WAsP computational model. The terrain roughness was described based on the conventions of roughness classes presented in the European Windatlas (Troen and Petersen, 1988). The terrain conditions have been described by classifying roughness within 12 sectors of 30° each. A detailed subsequent classification of roughness parameters has been performed on the base of aerial photographs and digitized topographical maps (1:25.000). Up to five changes in roughness values have been considered within a radius of 20 km around the study site: open farm land sparsely interspersed with small trees, villages, forested areas and water areas. No considerable obstacles, which could obstruct the wind flow, have been observed within 1.000 m radius from the met mast locations.

Deterministic prognoses of the state of the atmosphere are limited to a few days in advance. The chaotic dynamics of the system imposes these narrow limits; for larger intervals statistical statements may be derived only. To get an estimate of the future average wind conditions being expected in a certain area, usually wind data taken in the past has been applied. Since wind conditions may vary considerably from year to year, it is necessary to consider periods of sufficient length (>10 years) both for the measurements and for the prediction time. For such longer periods, the assumption that the wind conditions do not vary any more is usually taken. The past is projected into the future. In climatological science such a procedure is called persistence forecast. At least for the areas outside the tropics it yields satisfying results. But even averages for longer periods are not constant in time, although the fluctuations become smaller for extended averaging periods. Due to that, a profound persistence forecast in a climatological sense is obtained only when the variability range of the expected wind conditions is determined also and included into the uncertainty considerations.

A scientist has two possibilities to evaluate the wind conditions at a physical site: either he can use a wind measurement taken directly at the site or he has to apply a mathematical process which is able to transfer long-term data from a reference station nearby into the characteristic conditions at the site by using the so called WINDATLAS Method (Petersen et al., 1981; Nielsen and Chun, 1994). The Danish National Research Centre in Risø, Denmark, has studied a variety of long-term wind data from several European countries with respect to their applicability for wind energy purposes (Troen and Petersen, 1988). A physical method has been worked out which allows for the transfer of measured wind speeds from a certain measuring point to another site or even a whole region. An overview sketch of the method is shown in Figure 2.

Wind data from a meteorological station with its characteristic terrain conditions (obstacles, roughness and orography) are transformed into regional wind climatology. This so called WINDATLAS represents regional wind climatology when all local topographic conditions are removed and may be understood as the geostrophic wind of the free atmosphere above the boundary layer. By using such a regional wind statistics as the physical wind supply – with regard to the Weibull parameters related to direction – the wind climate of the considered microsite can be determined by invoking the specific topographical conditions for that point and nearly each height of the site (see downward arrow in Figure 2). These transformations are performed by the simplified linear flow model WAsP which has been conceived for simple and moderate complex terrain such as low mountain ranges. The method has been developed over a long period and has been applied successfully in numerous cases. It may be viewed as the current state-of-the-art of technology.

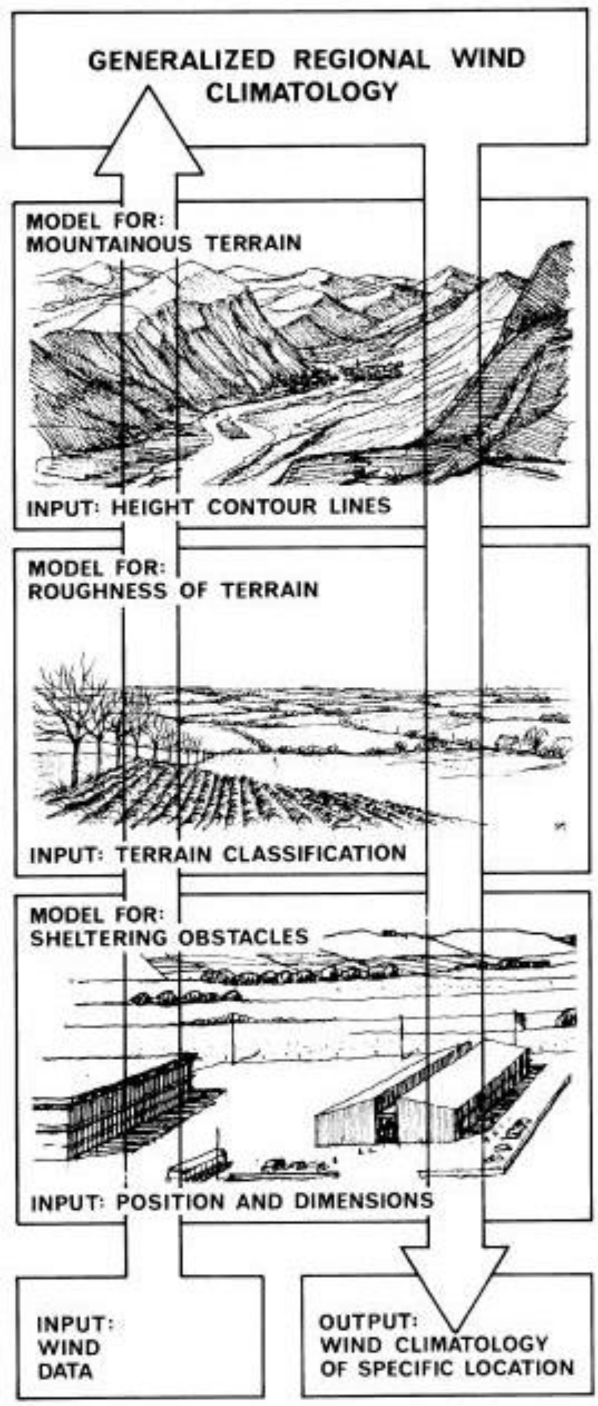

Fig. 2 The WINDATLAS method of WAsP for the evaluation of the wind potential of individual sites (*Source: Troen and Petersen, 1988*).

It has to be considered that every physical model is just an image of reality which is valid only under specific circumstances and might afflicted with uncertainties which have to be part of the analyses. On the one hand uncertainties exist within the method itself such as the representativeness of the chosen wind statistics or the accuracy of terrain description. The WAsP-Model is hardly applicable in extremely complex terrain as its linear assumption is not able to account several physical phenomena e.g. flow separations at steep edges. Furthermore, the effect of annual variation of the wind conditions is not covered by this analysis method. The WINDATLAS-method has been designed for the surface boundary layer, which is typically 50-80 m thick, but the obtained results given by the model for bigger heights were also fairly good. Thus, these calculations may be viewed to be conservative in general and the connected uncertainties may be tolerable.

Results & Discussion

The measurement masts are located on the highest and most exposed areas to dominant winds within the Southern Bârlad Plateau, in the close vicinity of the Prut river valley, which determines the acceleration of the wind fields with 5-10% in comparison with the neighboring areas. Towards all directions, the closer vicinity exhibits just moderate inclination of all adjoining slopes. The surroundings of the measurement sites are characterized by arable terrains which are intensively used for crops. No observable obstacle is found within a considerable radius of about 2 km around the two measurement sites. The wind measurements are similar regarding the measurement system and assembly.

Wind measurements quality assessment

Due to small gaps occurring in the winter months, as a result of freezing events and the corresponding icing of the sensors, the total data availability for all measurement levels during the analyzed period is at 98.7% for WM1 mast and 94.7% for WM2 mast.

In order to evaluate if the wind fields are relatively consistent within different locations of the Southern Bârlad Plateau, we performed a correlation study of wind speeds and directions measured at the two studied sites. To detect possible measuring errors and to check the quality of the wind measurement, the data of the wind sensors were also compared among each other. The 10 min. means of wind speed and wind direction at the different measuring heights and sites show a quite similar temporal evolution confirming the plausibility of the recorded sensor signals (Figure 3). Correlation between the wind speed measurements at 50 m at the two sites, WM1 and WM2, amounts to 0.89 (Figure 3A), which has to be rated as excellent regarding the comparatively short averaging interval of 10 minutes and the large distance of about 11.7 km between the two sites (Figure 1). Related to the particular measurement site WM1, the correlation between the recordings amounts 0.999 concerning the two sensors at identical height level (50 m a.g.l.) and 0.995 for 10 m height difference (50 m and 40 m; Figure 3B). These correlations indicate an excellent relationship between the different measurement levels at the two masts and, therefore, confirm the high quality of the wind measurements.

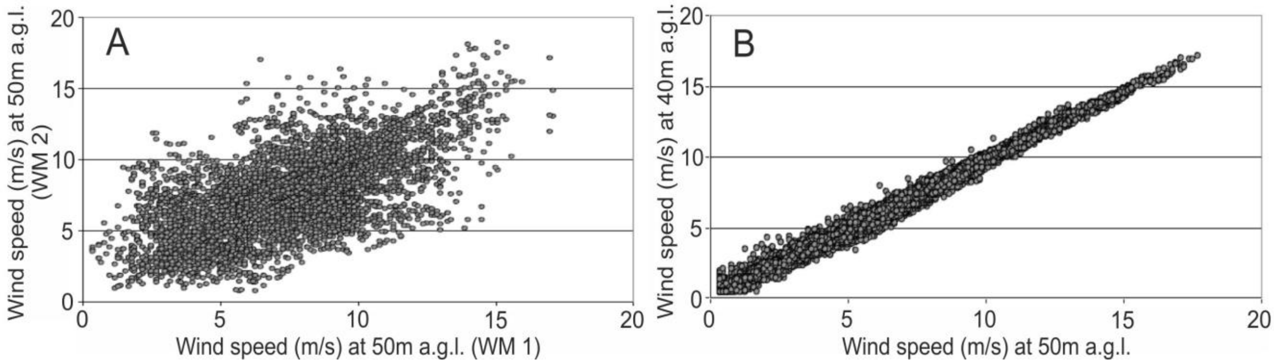

Fig. 3 Correlations of measured 10 min. means of wind speed for: A) WM1 vs. WM2 masts at 50 m a.g.l. and B) WM1 mast at 50 m vs. 40 m a.g.l.

The recorded time series at the different measurement heights at WM1 and WM2 locations have been compared with NCAR reference weather analyses data and to observations recorded at the Galați meteo station. All the reference data showed relatively good correlation with the measurement data on a 6-hourly basis. With regard to the total measuring period of app. 2 years, the NCAR Reanalysis data show a correlation of about 0.65, while the correlation of the recorded time series with the observations at the Galați meteo station is 0.70. In summary, all recorded time series at both measurement sites can be rated to be plausible as self-consistency checks and comparisons to reference data showed.

Wind measurements results

After verifying the measured data, the time series of the 10 min. average values have been classified according to wind speed (using the METEO module of WindPro 2.7). As a result, the measurements can be presented in the form of a two-dimensional frequency of occurrence distribution. For further mathematical processing, this distribution is approximated by a two-parametric distribution function, the so-called Weibull distribution with scale parameter A and form factor k (Figure 4). Parameter estimation is done energy-weighted, which means that the adaptation to the measured values is best for high wind speeds.

The average wind speed measured during the analyzed 23.3 months (November 2008 – November 2010) was estimated to be 6.1 m/s for WM1 and 6.4 m/s for WM2 at 50 m and 60 m a.g.l. respectively. The two sites show a considerable difference in the variety of wind speeds for the upper measurement levels. The results for the WM1 site, covering the measurement period, are presented in Table 2 and structured by the individual height levels.

The sector wise Weibull-adjusted average wind speed and average energy density for 50 m a.g.l. at WM1 mast are presented in Table 3. The highest average wind speeds of about 6.5 m/s are observed both in the northern directions (from NW to NE) and in the SW direction. The lowest average wind speeds of about 5.0 – 5.5 m/s come along with the eastern and western winds at both measurement sites.

Table 2: Average wind conditions at WM1 mast measured between November 2008 and November 2010 at 20, 40 and 50 m heights and estimated using the WAsP Interface module of WindPro 2.7 (WAsP long-term correlation) at 100 and 120 m heights. Calculation of the power density and energy density is based on an air density of 1.206 kg/m^3, mean temperature of 10.9° C and a mean air pressure of 980 hPa at 120 m height level, based on the measurements at the wind measuring mast during the studied period of time.

Height (m)	Mean wind speed (m/s)	Weibull Parameters		Wind energy density (kWh/m^2)
		A (m/s)	k	
20	5.06	5.7	2.07	1278
40	5.86	6.6	2.26	1827
50	6.04	6.9	2.32	2032
100	7.27	8.2	2.52	3188
120	7.71	8.7	2.48	3850

Table 3: Sector wise measurement results at WM1 site at 50 m a.g.l. (November 2008 – November 2010).

Sector	Frequency (%)	Wind speed (m/s)	Weibull k-parameter (m/s)
N	17.9	6.73	2.5
NNE	10.9	6.43	2.34
ENE	6.1	5.87	2.42
E	3.9	5.59	2.35
ESE	8.3	5.99	2.61
SSE	7.5	6.27	2.73
S	8.2	6.33	2.65
SSW	10.1	6.18	2.02
WSW	4.8	5.0	2.47
W	5.3	5.03	2.47
WNW	7.1	5.7	2.24
NNW	9.8	6.31	2.39
Total	100	6.13	2.33

The frequency of wind direction, as well as the sector-depending energy contribution at 50 m height level during the measurement period at WM1 site is given in Figure 4. At both sites, the prevalent winds are coming from northern directions, with total frequencies of about 45%. A second maximum occurs from the southern directions, with total frequencies of about 30% (Table 3). The highest mean wind speeds during the measurement period are observed in the sectors North to NNW and South to SSW. Associated with the high frequency of occurrence, these sectors share the highest proportion in the wind energy distribution. About 55% of the wind energy content at WM1 site is associated with the North to NNW sectors and about 30% with the south to SW sectors (Figure 4).

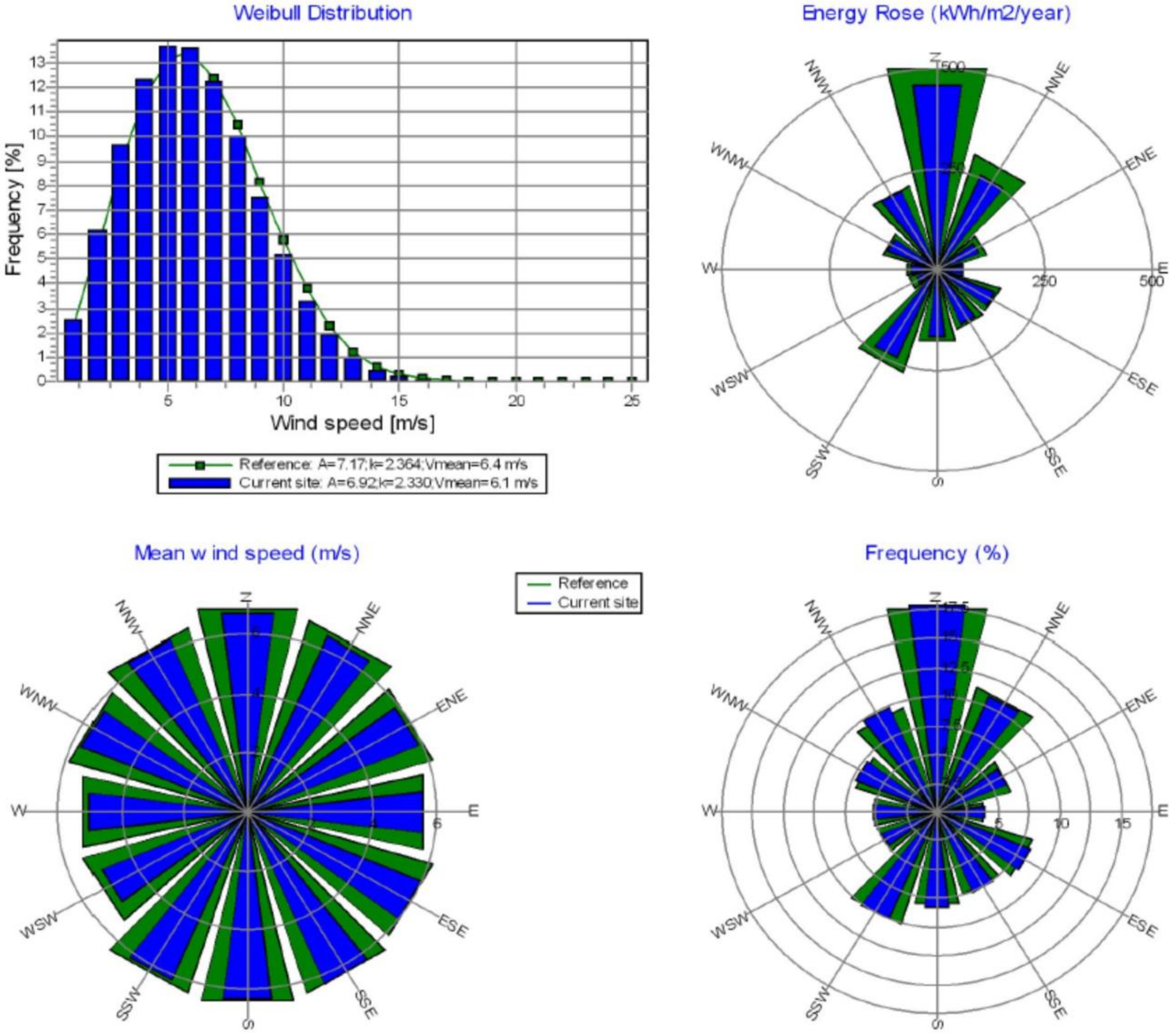

Fig. 4 WAsP Interface module results – Wind data analysis (50 m a.g.l.) for WM1 mast: sector wise frequency of occurrence, mean wind speed and energy distribution.

Long-term wind conditions and adjustments

Wind conditions may vary considerably from one year to another. Therefore, it is required to assess the long-term wind conditions at a site to get a reasonable base for wind energy planning considerations. Since a project related wind measurement is usually time-limited, an adjustment with respect to long-term climate data is required. The wind measurements cover 23.3 months of data, which represent fairly good the full seasonal cycle. However, the year to year variability can be significantly high. Thus, a long-term correction was performed. This was done by taking suitable reference data into account, which are representative for the same wind climate and cover a long-term period, including the short-term measurement. For that purpose, large-scale meteorological analyses data provided by NCAR (Figure 5A) and long-term observations at the Galați meteo station have been taken into account and analyzed individually (see Data & Methods section for a description of the datasets).

Considering that the complexity of the topographic conditions of the area under investigation is poor, NCAR Reanalysis data can be regarded to be suitable concerning the long-term adjustment of the measured time series. The correlation of the NCAR time series at 42 m height and the wind measurements at 50 m height at WM1 site (23.3 months) is 0.71, on the basis of 6-hourly means, and 0.8, on the basis of monthly means (Figure 5B,C). The observations from the Galați meteo station should be more appropriate for long-term correction purposes concerning WM1 site, indicated by the high correlation with the measurement data of about 0.72. However, due to the very poor data availability of only 63% over the long-term period, the observed time series at the meteo station were not appropriate to constitute a basis for a long-term approach. Moreover, this time series show a significant temporal trend which is local and human-induced. Since the observed wind speeds become significantly poorer since the beginning of 2002, it is strongly expected that the location of the station has been affected by new buildings erected nearby. Hence, in the following, the long-term time series deduced from the local NCAR data have been used for all calculations regarding the long-term wind and energy yield conditions at the study site.

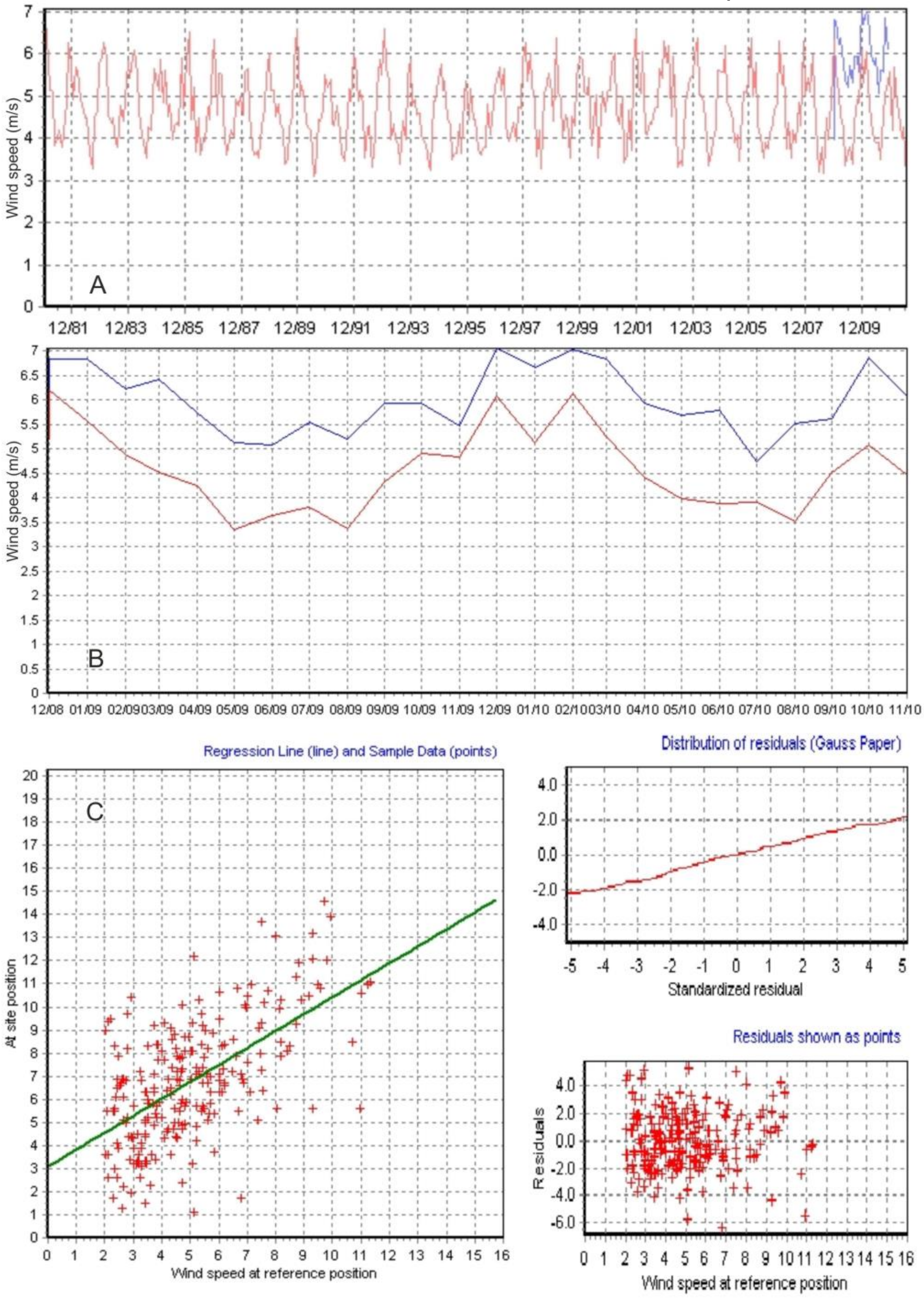

Fig. 5 MCP module results – Wind speed correlations between WM1 (*blue line*) and NCAR long-term (*red line*) data series for: A) 1981 – 2010 interval and B) 2008 – 2010 measurements period. C) Regression analysis of the NCAR and WM1 wind speed time series.

To perform the transfer of the short-term measurements at WM1 site to the long-term representative period, a Measure-Correlate-Predict (MCP) method was performed using the MCP module of WindPro 2.7. For this study, a sector-dependent regression model, based on data of the measurement and the data of the reference index, was applied. A long-term time series representative for the measuring site $x^{long}(t)$ is reconstructed from the given long-term reference dataset $y^{long}(t)$:

$$x^{long}(t) = F(y^{long}(t))$$

The transfer function $F = F(x^{short}(t); y^{short}(t); a)$ is estimated from the concurrent short-term wind speed values and directions. Here, a sector depending scaling of mean and variance according to the standard deviation approach has been chosen. This model allows a sector-dependent and energy consistent conversion of wind speed and the reconstruction of a time series and frequency distribution that represents the long-term time frame. Deviations of the directional distribution between short-term and long-term period might be considered also. For reconstruction, we have used data on a 6-hours average basis, but included corrections for the variability lost due to this averaging to adapt the energy level to the quality of the 10 min. averages of the measurement. The 30 years period, covering 1981 - 2010 interval, had been chosen as long-term reference period (Figure 5A).

By following the described approach, a long-term adjustment has been carried out for the recorded time series over 23.3 months (2008-11-30 until 2010-11-08) for the 50 m at the WM1 site (Figure 5B). The resulting data reconstructions for the considered measuring levels give an acceptable correlation to the real recordings at WM1 site during the regarded measurement period of about 0.7 (Figure 5C). The measured average wind speed over the regarded measurement period is reproduced with accuracy better than 1 %. Almost the same accuracy has been obtained for the energy content of the wind. It could be reproduced by a small range of deviation from 98.0% up to 99%. The newly obtained 30 years long-term wind conditions at the WM1 site, deduced from the above described method, with respect to the considered measuring heights, are very close to the short-term (2008 – 2010) values. The calculated average long-term wind speed at the 50 m height level is slightly higher than for the short-time (6.13 m/s in comparison with 6.04 m/s). The short-time average wind speed over the regarded measurement period of 23.3 months from November 2008 until November 2010 corresponds with about 99% of the expected long-term level. This relation translates to energy conditions for the long-term, which are about 0.6% higher than for the regarded measurement period.

Vertical extrapolation of wind statistics. Wind energy potential assessment

The long-term adjusted wind data series of WM1 site has been transformed into a wind statistics (using STATGEN module of WindPro 2.7) derived for the 50 m measurement level. This wind statistics has been generated according to the WINDATLAS method by taking into account the local orography, roughness and obstacles (see Data & Methods section). It includes the vertical profile of Weibull parameters A and k and of the long-term mean wind speed at site location (Figure 6). The wind shear exponent of the vertical profile is 0.21 (power law profile), while the roughness length is 0.15, corresponding to a roughness class of approximately 2. These values are almost identical to the values obtained during the measurement period.

Furthermore, vertical extrapolations up to 150 m a.g.l., based on the individual wind statistics and vertical profile, were computed (Table 4). At both measurement sites, the calculated wind parameters and energy deviate by about ±1%, largely confirming the derived terrain model and the reliability of the vertical extrapolation with regard to the observed wind profile. The results of these extrapolations show almost the same wind and energy parameters as for the short-term measurements, demonstrating the relative consistency of wind flows within the Southern Bârlad Plateau at multi-decadal scale.

Table 4: Calculated vertical wind profile values for the long-term wind statistics at WM1 site.

Height (m)	Mean wind speed (m/s)	Weibull Parameters		Wind energy (kW/m²)
		A (m/s)	k	
50	6.12	6.9	2.35	2023
60	6.38	7.2	2.42	2233
70	6.61	7.4	2.49	2425
80	6.81	7.7	2.56	2602
90	7.0	7.9	2.63	2768
100	7.17	8.1	2.7	2925
110	7.33	8.2	2.77	3074
120	7.49	8.4	2.84	3217
130	7.63	8.6	2.91	3354
140	7.77	8.7	2.98	3487
150	7.9	8.8	3.05	3617

After obtaining the vertical profile of wind statistics, we mapped the long-term wind resources within the study area (Figure 7) using the RESOURCE module of WindPro 2.7. This module extrapolates the wind statistics of each measurement point on large neighboring surfaces, function of the influence of orography and roughness on wind flows. Analyzing Figure 7, we can see that the study site has a very good wind energy potential, proved by high long-term averaged wind speeds: the values are comprised between 7 and 8 m/s at 120 m height level. These values can be easily transformed into wind energy values and mapped using the RESOURCE module, obtaining a map similar with the one presented in Figure 7.

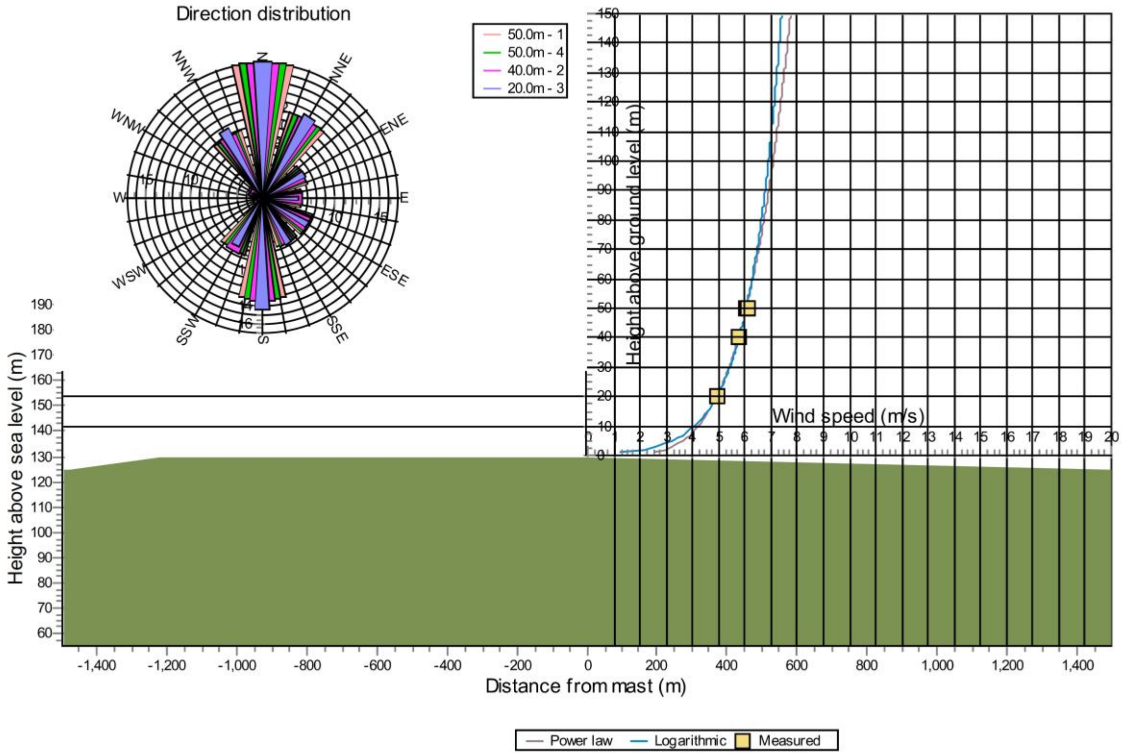

Fig. 6 Mean long-term vertical wind profile and terrain profile for the most frequent sector of height (50 m a.g.l. – North) for WM1 site.

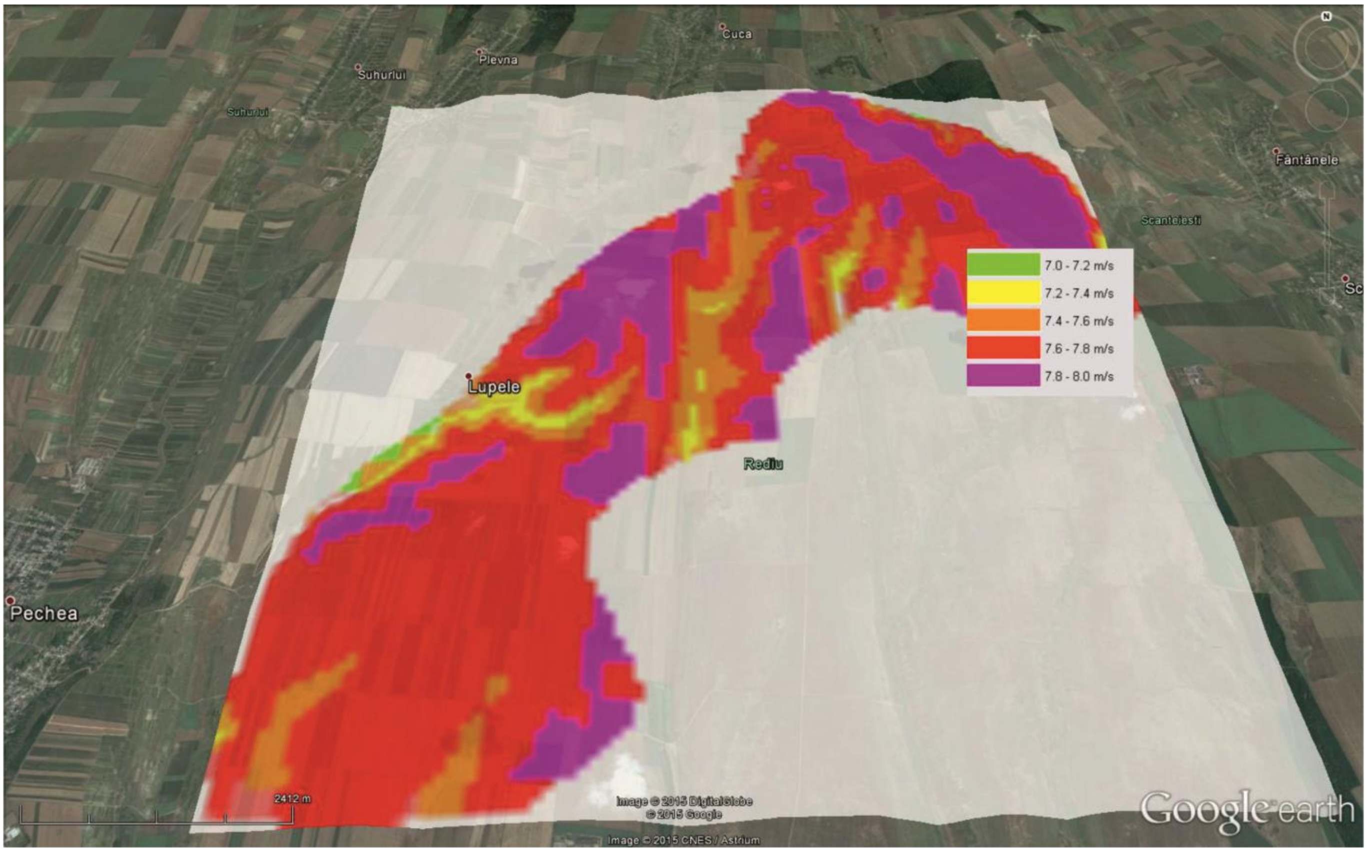

Fig. 7 Long-term wind resources at 120 m a.g.l. within the study area.

Furthermore, the power curve of the chosen Wind Turbine Generator (WTG) type, specified by the manufacturer or measured by independent consultants, has to be considered in energy yield calculations. By linking the statistics of the wind conditions with the power curve, the expected energy production may be determined. In conclusion, in order to determine the energy yield for a special WTG type according to the calculated wind resources, the Weibull distribution of the wind estimate has to be multiplied and integrated with the power curve of the WTG considering the whole spectrum of wind speeds (Petersen at al., 1998). This way, the estimated annual energy production of each WTG in a specific wind farm is representative for long-term wind conditions.

Conclusions

The present article describes a complex methodology for quantifying the wind conditions and energy potential of large areas based on several years of high resolution in-situ measurements (in multiple points), adjusted for long-term reliability using global climatic datasets or multi-decadal meteo station data.

After quality assessment, the in-situ measured data were analyzed and adjusted to long-term reference using a mathematical process (WINDATLAS Method) which is able to transfer long-term data from a reference station nearby into the characteristic conditions at the study site, taking into consideration the orography, roughness and obstacles which are influencing the wind flows in the area. The newly obtained long-term wind statistics, comprising sector wise Weibull distribution, mean wind speed, frequency of wind direction and wind energy distribution, were transformed into wind speed and energy maps, which were further used for the characterization of the wind energy potential within the location of interest.

Based on the wind characteristics evaluated within the representative study site, we can conclude that the Southern Bârlad Plateau has very good wind energy potential as the long-term averaged wind speeds range between 7 and 8 m/s at 120 m a.g.l. (similar to the values registered in Dobrogea region), with corresponding wind energy values higher than 3000 kWh/m^2 at the same height level. The prevailing winds are coming from northern and southern directions (relatively unidirectional on the same axes) and the long-term wind speeds are relatively constant at multi-annual scale, which means that this area is relative easily predictable for future wind conditions, being also highly suitable for the development of Multi-Megawatt wind farms.

Further on, the above presented local wind conditions and statistics can be integrated into energy yields for the WTG sites at the planned hub heights. This gives a strong applied character to the present climatic study, as its results can be further used in energy production estimates and feasibility studies for wind farms.

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References

Bataineh, K.M., & Dalalah, D. (2013). Assessment of wind energy potential for selected areas in Jordan, *Renewable Energy*, 59, 75-81.

Carta, J.A., Velázquez, S., & Cabrera, P. (2013). A review of measure-correlate-predict (MCP) methods used to estimate long-term wind characteristics at a target site. *Renewable and Sustainable Energy Reviews*, 27, 362-400.

Colesca,S.E., & Ciocoiu,C.N. (2013). An overview of the Romanian renewable energy sector. *Renewable and Sustainable Energy Reviews*, 24, 149-158.

Climate of Romania (2008), Edit. Academiei Române, Bucharest (in Romanian).

Mihailescu, L., (2009). Wind power in Romania. *Renewable Energy Focus,* 10(4), 44-46.

Nawri, N., Petersen, G.N., Bjornsson, H., Hahmann, A.N., Jónasson, K., Bay Hasager, C., & Clausen, N.E. (2014). The wind energy potential of Iceland, *Renewable Energy*, 69, 290-299.

Nielsen, P., & Chun, S. (1994). WINDATLAS-SYSTEM user guide, Energi- og Miljødata (EMD).

Nielsen, P., & Chun, S. (2000). WindPRO manual, Energi- og Miljødata (EMD).

Petersen, E.L., Troen, I., Frandsen, K., & Hedegaard, K. (1981). Windatlas for Denmark - A rational method for wind energy siting, Risø-R-428 Report, Risø National Laboratory, Denmark.

Petersen, E., Mortensen, N.G., Landberg, L., Hojstrup, J., & Frank, H. (1998). Wind Power Meteorology, *Wind Energy*, 1, 25-77.

Troen, I., & Petersen, E.L. (1988). European Wind Atlas, Risø National Laboratory, Denmark.

Vespremeanu-Stroe, A., & Tătui, F. (2011). North-Atlantic Oscillation signature on coastal dynamics and climate variability of the Romanian Black Sea Coast. *Carpathian Journal of Earth and Environmental Sciences*, 6 (1), 135-144.

Vespremeanu-Stroe, A., Cheval, S., & Tătui, F. (2012). The wind regime of Romania – characteristics, trends and North Atlantic Oscillation influences. *Forum Geografic*, XI (2), 118-126.

Weekes, S.M., & Tomlin, A.S. (2014). Data efficient measure-correlate-predict approaches to wind resource assessment for small-scale wind energy, *Renewable Energy*, 63, 162-171.