DIRECT ASSESMENT OF WIND ENERGY

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Această lucrare prezintă analiza măsurărilor de vânt realizate în zona Dobrogea, în patru locații distincte, pe o perioadă de 11 luni. Datele provenite din măsurări, sunt prelucrate si ajustate pentru condițiile de lungă durată, prin corelarea cu date provenite din analiza NCAR/NCEP pentru 30 de ani, precum si o corelație cu datele achiziționate pe o durată de 3 ani, în portul Constanta. O modelare a vântului a fost realizată folosind soft-ul de ultimă generație WindSim CFD, pentru a realiza o hartă preliminară. Folosind datele obținute, au fost alese clasele de turbine eoliene optime pentru fiecare locație.

This paper presents and analyzes the wind measurement data of four measurement masts after a period of approximately 11 months. The measurement data is controlled and adjusted to long term conditions by correlation with 30-year NCAR/NCEP reanalysis data as well with 3 years data from one tower at Constanta port. Based on the processed measurement data, wind modeling is performed with the state-of-the-art Computational Fluid Dynamics software WindSim, in order to establish preliminary wind resource maps for every area. Based on these maps, different classes of wind turbines, were established for each area, in order to get optimal efficiency.

Keywords: wind power, wind turbine, measurement mast

1. Introduction

Wind power meteorology has evolved as an applied science, firmly founded on boundary-layer meteorology, but with strong links to climatology and geography. It concerns itself three main areas: siting of wind turbines, regional wind resource assessment, and short-term prediction of the wind resource[1].

The data used in wind power meteorology stem mainly from three sources: on-site wind measurements, the synoptic networks, and the re-analysis projects. Wind climate analysis, wind resource estimation and siting further require a detailed description of the topography of the terrain –with respect to the roughness of the surface, near-by obstacles, and aerographical features.

With respect to wind power meteorology, siting is defined as estimation of the mean power produced by a specific wind turbine at one or more specific

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locations A full siting procedure includes considerations such as the availability of power lines and transformers, the present and the future land use, and so on.

Regional assessment of wind energy resources means estimating the potential output from a large number of wind turbines distributed over the region. Ideally, this results in detailed, high resolution and accurate resource maps, showing the wind resource, yearly and seasonal, the wind resource uncertainty, and areas of enhanced turbulence.

The national wind energy programs, which were initiated in a number of countries in the 70s, typically included national wind resource surveys. Among these, probably the best known are the Wind Energy Resource Atlas of the United States by Pacific Northwest Laboratory and the Wind Atlas for Denmark by Riso National Laboratory, both published in 1980. In addition to these atlases a number of so-called siting handbooks were produced; most notably in the USA (1977) and (1980), in Canada (1984), and in the Netherlands (1986). The Danish Wind Atlas and later the European Wind Atlas (1989) serve both purposes, as wind resource atlas and siting handbook.

2. Description of Wind Measurement

A number of wind measurement masts was install in the area of northern Dobrogea. Figure 1 and Table 1 show measurement sites and modeling areas which are taken into consideration in this paper.

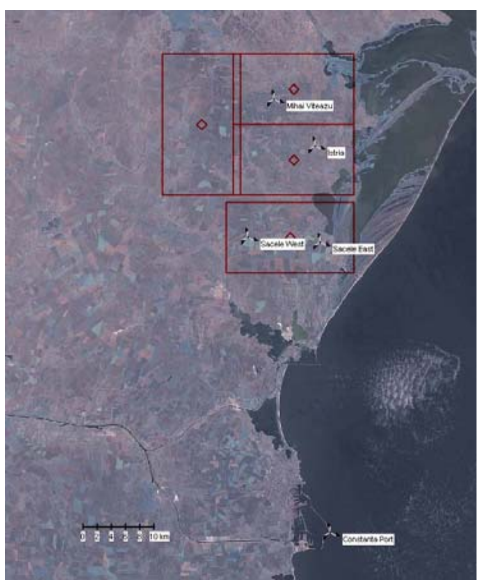


Fig. 1. Satellite picture (Landsat) [2] of northern Dobrogea with the regions of the wind measurements taken into account in this paper. The boxes show the boundaries of the modeling areas.

Table 1

Coordinates of the measurements mast

Site name	Coordinates (UTM WGS 84, zone 35)	Altitude
Constanta Port	636’635/4’885’355	9 masl
Sacele East	635’234/4’926’364	54 masl
Sacele West	625’009/4’927’041	154 masl
Istria	634’571/4’939’988	100masl
Mihai Viteazul	628’712/4’946’589	163 masl

The sensors and instruments used for measurement, were the same type in every mast. The equipment used in the Constanta Port mast, is presented in table 2.

Table 2

Instruments and sensors at Constanta Port

Parameter	Instrument type	Measurement height [m]	Direction	Boom
Wind speed	NRG 40 MAX	39,6	315°	1,1
Wind speed	NRG 40 MAX	39,6	143°	1,1
Wind speed	NRG 40 MAX	28,6	313°	1,1
Wind speed	NRG 40 MAX	28,6	133°	1,1
Wind speed	NRG 40 MAX	10,7	312°	1,1
Wind speed	NRG 40 MAX	10,7	140°	1,1
Wind direction	NRG 200P	39,9	166°	Top
Wind direction	NRG 200P	39,6	180°	0,3
Relative humidity	RH-5	2	-	-
Pressure	NRG BP20	2	-	-
Temperature	NRG 110S	3	-	-
Data logger	NRG Symphonie	-	-	-

In order to ensure intercompatibility between measurement sites, only the data of October 12, 2006, to September 23, 2007**,** was used for all sites for the further analyses in this paper.

The following procedure was applied to establish clean data sets for all measurement sites:

1. Definition of reference sensors: For each mast a reference wind speed and direction sensor was defined. This is usually the topmost sensor. If two sensors are at the same height, the one less influenced by the mast was chosen.

2. Correction of reference sensor values by parallel measurements: If the reference sensor is influenced by the mast (as in Constanta Port and Istria), all data within a 30° angle of the boom's direction was adopted from its parallel sensor (at the same height on the other side of the tower).

3. Reconstruction of missing values within mast: If available, missing values of the reference sensors were reconstructed using measurements at the

same mast. For wind speed, correction factors were determined during the mutual measurement period and used to extrapolate measurements during the missing periods.

4. Reconstruction of missing values from other masts: For Sacele West and Mihai Viteazul, which were both sabotaged, it was necessary to reconstruct missing values with measurements from other masts. Wind data from both masts correlated best to measurements from Istria (correlation coefficients of 0.80 and 0.88 for 10 minute values, respectively). For wind speed, correction factors were determined during the mutual measurement period and used to extrapolate measurements during the missing periods. Wind direction values were adopted without any modifications as they correlated well (Figure 2).

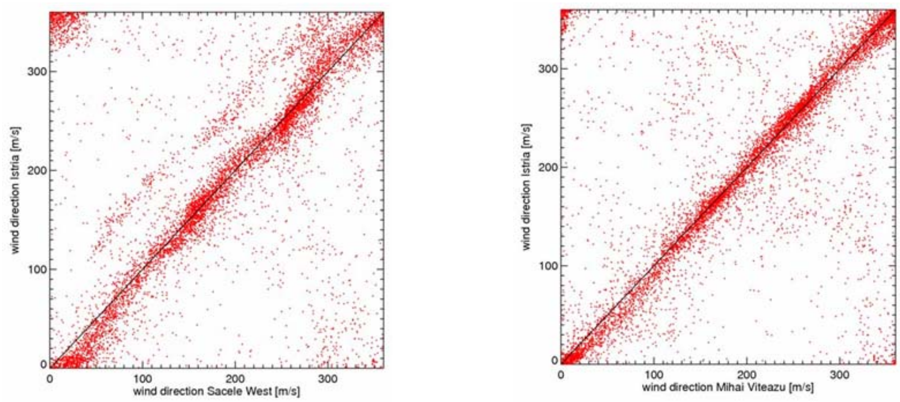


Fig. 2. Correlation of wind direction data (hourly means) between Istria and Săcele West (left), and Istria and Mihai Viteazul (right).

With this procedure it was possible to establish a clean data set with 100% availability for each measurement site for the period of 12.10.2006 - 23.09.2007 (29.09.2004 - 23.09.2007 for Constanta Port). These clean data sets were used as the basis for all further data analyses.

3. Results of Wind Measurements

In the following figures show monthly wind speeds, wind roses and wind speed distributions for Constanta Port measurement site. For simplification, the measurement heights are rounded to 40 m in these figures.

Table 3 show the monthly mean wind speed at all sites from 12.10.2006-23.09.2007

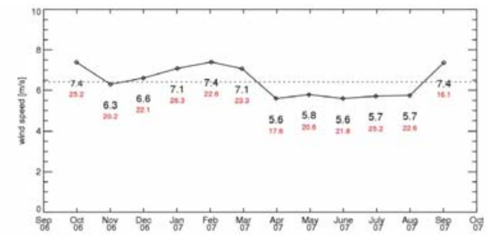


Fig. 3. Monthly mean wind speeds as well as 2 seconds gusts at 40 m at Constanta Port for the period 12.10.06-23.09.07.

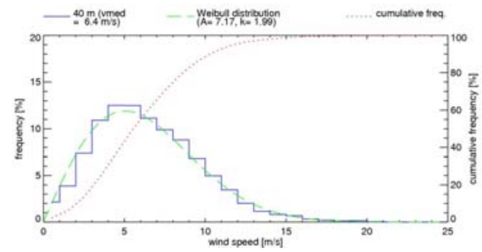


Fig. 4. Wind speed distribution at 40 m at Constanta Port for the period 12.10.06-23.09.07 including approximated Weibull distribution.

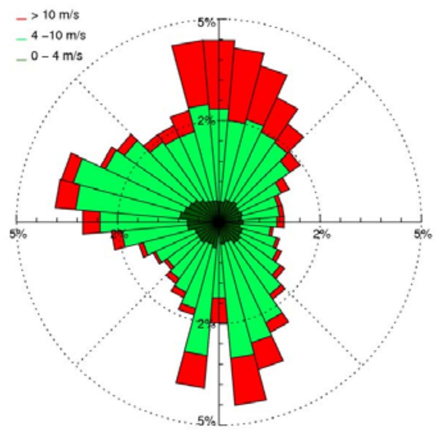


Fig. 5. Wind rose at 40 m at Constanta Port for the period 12.10.2006-23.09.2007.

Table 3

Monthly mean wind speed at 40 m. Bold values show the 11-month-mean at 40 m and the corresponding value at 100 m (hub height)

	Constanta	Sacele East	Sacele West	Mihai Viteazu	Istria
Oct 06	7,4	6,3	6,7	6,4	6,8
Nov 06	6,3	6,2	6,3	6,8	6,5
Dec 06	6,6	6,5	6,5	7,2	7,2
Jan 07	7,1	8,3	7,8	9,2	8,7
Feb 07	7,4	7,0	7,2	7,6	7,4
Mar 07	7,1	6,8	7,3	7,0	6,9
Apr 07	5,6	6,0	6,3	6,2	6,4
May 07	5,8	5,9	6,6	5,9	5,9
Jun 07	5,6	5,8	6,3	6,1	6,2
Jul 07	5,7	6,2	6,5	6,6	6,6
Aug 07	5,7	5,7	6,2	5,6	6,3
Sep 07	7,4	7,5	7,1	7,5	7,9
Mean (40 m)	6,5	6,5	6,8	7,1	6,9
Mean (100 m)	7,5	7,6	7,7	7,8	7,9

4. Long term Wind Statistics

As suitable, consistent long-term data is not available from meteorological stations in Romania; long term wind statistics were compiled based on NCAR/NCEP reanalysis data [3]. The NCEP/NCAR reanalysis dataset is a continually updating gridded data set representing the state of the Earth's atmosphere, incorporating observations and global climate model output dating back to 1948. The advantage of this dataset is that it provides homogeneous, consistent and very long term data world wide.

Surface wind speed NCAR/NCEP reanalysis data was downloaded for the two grid points at 45°N/27.5°E and 45°N/30°E. Reanalysis data is available in time steps of six hours. Correlations with these values as well as daily means were performed with data from the five wind measurement sites (Table 4).

Table 4

Correlation of NCAR/NCEP reanalysis surface as well as Constanta wind speed data with the measurement site for the period 12.10.2006-23.09.2007

Measurement site	Correlation site	Correlation of 6-hour values (coefficient)	Correlation of daily means (coefficient)
Constanta Port	Reanalysis grid point 45°N/27,5°E	0,55	0,60
Sacele East		0,57	0,71
Sacele West		0,61	0,74
Mihai Viteazu		0,60	0,71
Istria		0,58	0,70
Constanta Port	Reanalysis grid point 45°N/30°E	0,61	0,74
Sacele East		0,58	0,72
Sacele West		0,57	0,72
Mihai Viteazu		0,59	0,73
Istria		0,60	0,75
Measurement site	Correlation site	Correlation of 6-hour values (coefficient)	Correlation of daily means (coefficient)
Sacele East	Constanta	0,72	0,83
Sacele West		0,73	0,84
Mihai Viteazu		0,61	0,74
Istria		0,69	0,81

It was found that grid point 45°N/30°E correlates slightly better than grid point 45°N/27,5°E for all sites except for Sacele East. Correlation coefficients for daily means lie between 0,72 and 0,75 for the former grid point, which compares well with correlations usually found with meteorological stations in regions with a low measurement density. For reasons of intercomparability, it was decided to adopt grid point 45°N/30°E for all sites for long term calculations.

Figure 6 compares the long term monthly means with the monthly means during the measurement period for the reanalysis grid point 45°N/30°E. The grey lines in the background show the monthly means of the single years. For comparison, the red line shows the monthly means of the Istria measurements mast. Figure 7 shows the wind rose of the reanalysis data (45°N, 30°E) for the measurement period.

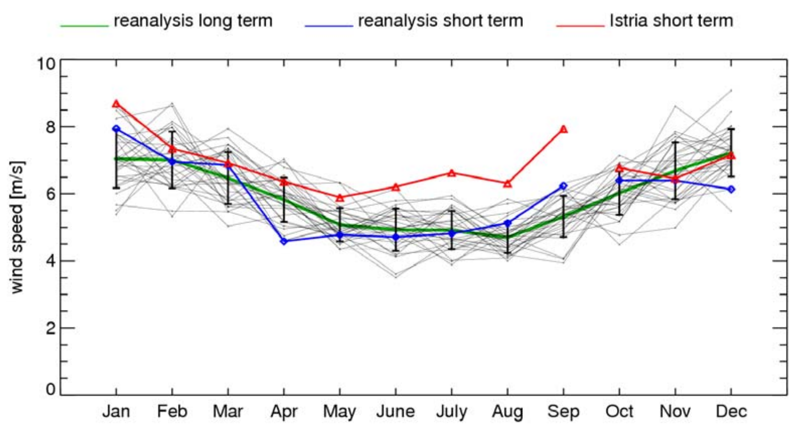


Fig. 6. Long term monthly means of wind speed (1977 - 2007, green) and its standard deviation (bars) as well as the monthly mean wind speeds of the measuring period (blue) at the reanalysis grid point 45°N/30°E.

Table 5 shows the correction factors for long term wind speed for the reanalysis data as well as the Constanta data. For modeling, the wind 30 year reanalysis factor (1.007) was applied. This means that mean long term wind speeds are expected to be 0.7% higher than wind speeds during the measurement period 12.10.2006 - 23.09.2007. Figure 8 show the resulting long term wind speed frequency distribution when applying the correction factor to the mast measurements. For modeling, the wind 30 years reanalysis factor (1,07) was applied.

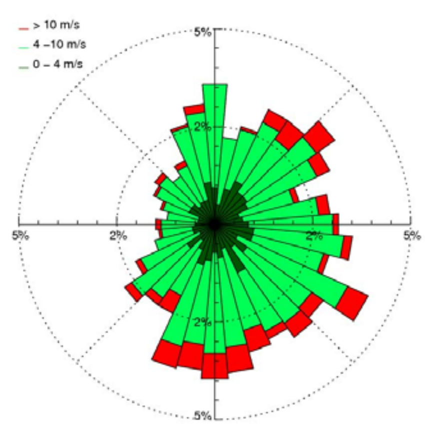
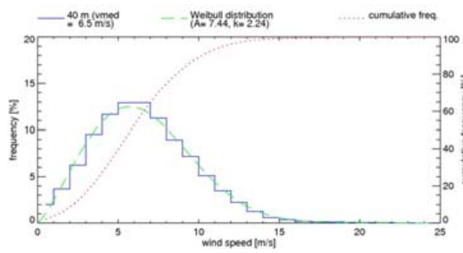


Fig. 7.Wind rose of the reanalysis data (45°N, 30°E) for the period 12.10.2006 -23.09.2007.

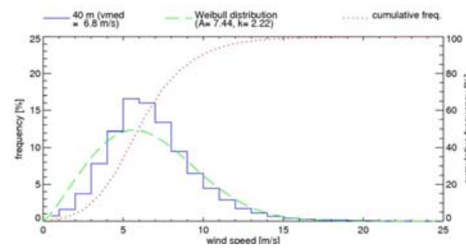
Table 5

Correction factors for the long term extrapolation of the wind measurements.

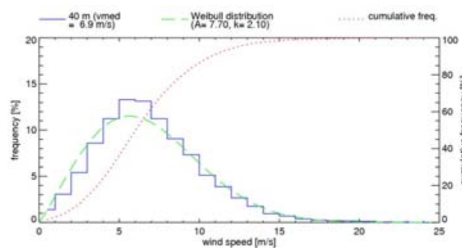
Site	v [m/s]	v [m/s]	Correction factor
Reanalysis 45°N-30°E 30 years	5.93	5.89	1,007
Reanalysis 3 years	5.96	5.89	1,012
Constanta 3 years	6.71	6.41	1,047



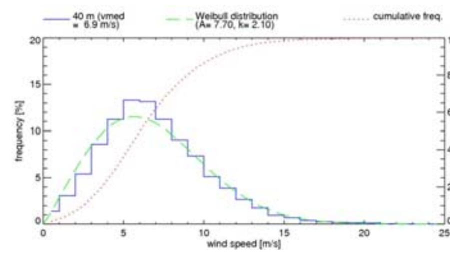
Săcele East



Săcele West



Mihai Viteazu



Istria

Fig. 8. Long term wind speed distribution at 40 m
including approximated Weibull distribution.

5. Wind Modeling

Methodology.

WindSim is based on the Phoenix 3D Reynolds Averaged Navier-Stokes solver. Solving the non-linear transport equations for mass, momentum and energy makes WindSim a suitable tool for simulations in both complex terrain, and in situations with complex local climatology.

In contrast e.g. to WAsP, which calculates wind statistics by parametrizing the influence of topography, roughness and obstacles, CFD modeling computes the three-dimensional wind flow field. It can be compared to a virtual wind tunnel.

Modeling was performed in one so-called nesting step for four regions. The nesting step enhances resolution for a smaller region of the base model. Nesting allows calculating high resolution results with acceptable computing resources. The model can thus be refined for the area(s) of interest. The first step includes the whole model domain. Here, very general boundary and initial conditions are assumed: vertical wind speed as log profiles up to a defined height and constant wind speed above. The results of this step are used as boundary and initial conditions for the second nesting step, which is performed for a smaller area at a higher resolution. In each step, three-dimensional wind fields are calculated for 12 wind direction sector (every 30°).

In order to compute the wind resources, a local long term wind climatology is introduced into the model. This climatology is split into the same wind direction sectors that are used for modeling. For all wind directions, the climatology's wind statistics are transferred to all other locations in the model domain by weighting it with the ratio of the computed wind speed between the climatology's location and the new location. Modeling was performed for every four areas.

Input data.

Topography. A digital elevation model with a horizontal resolution of 100 m was extracted from NASA SRTM data[4]. Roughness lengths were calculated from the 100 m CORINE land cover data set [5] using roughness lengths specified by TA Luft [6].

Wind climatologies. The long term wind climatologies were used. For the region of Sacele, both the climatologies of Sacele East and West were inserted. For Ramnicu a long term climatology was not available. Therefore the Istria climatology was transferred to this region. Climatology transfer is performed by extrapolating a climatology from measurement height to several hundred meters above ground (where small-scale topography plays a negligible role) in the nested model, then transferring it in the main model to the new region, and reinserting it into the target region’s nested model.

Boundary and initial conditions.

For the main model, boundary conditions for wind speed were set to vertical log profiles to a height of 500 m above ground and a constant wind speed of 10 m/s above that. For the nested models, boundary and initial conditions were interpolated from the parent models' results.

Results

Figure 9 to Figure 13 show the resulting wind resource maps for the four areas at 100 m above ground.

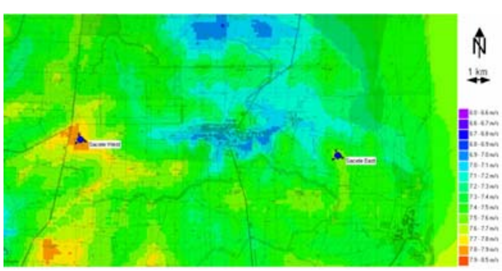


Fig. 9. Wind resource map of the Sacele area at 100 m above ground (modeled with the long term wind statistic of Sacele East). The positions of the measurement masts are marked in blue.

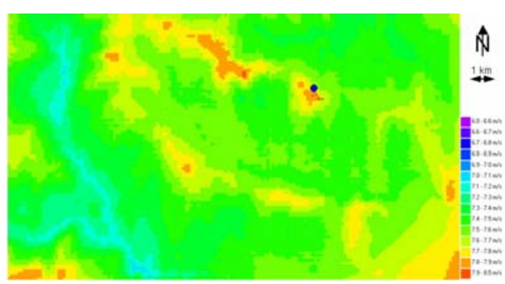


Fig. 10. Wind resource map of the Istria area at 100 m above ground (modeled with the long term wind statistic of Istria). The position of the measurement mast is marked in blue.

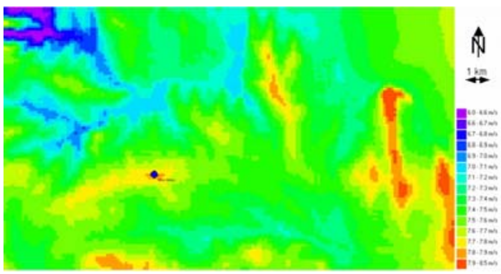


Fig. 11. Wind resource map of the Mihai Viteazu area at 100 m above ground (modeled with the long term wind statistic of Mihai Viteazu). The position of the measurement mast is marked in blue.

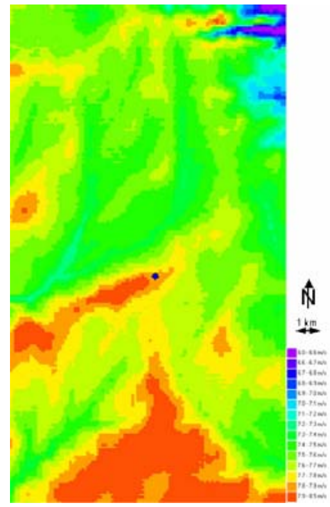


Fig. 12. Wind resource map of the Ramnicu area at 100 m above ground (modeled with the transferred long term wind statistic of Istria). The position of the transferred climatology is marked in blue.

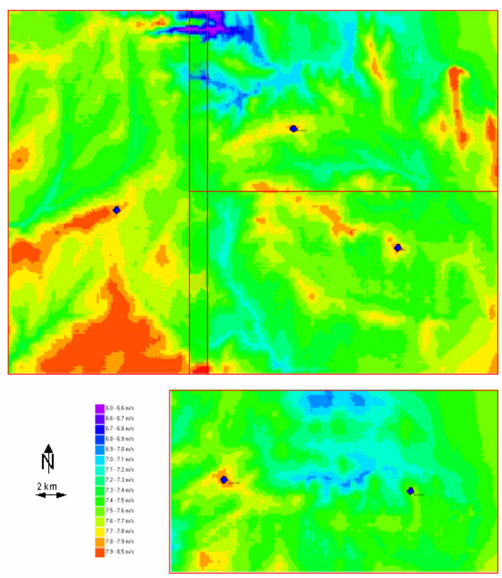


Fig. 13. Overlay with resource maps at 100 m above ground of all four modeled areas. The model boundaries are marked in red. The positions of the measurement masts are marked in blue

6. Conclusions

The large data base of wind measurements available for this report provided an excellent basis for an accurate study on the wind conditions in northern Dobrogea. The good correlation of the wind data between the measuring masts allowed filling data gaps without introducing large uncertainties. Nevertheless, in one data set (Sacele East) inconsistencies in the wind direction data were detected which could not be resolved. The measurement protocol contained no entry which could have explained for these inconsistencies.

For the whole measurement campaign, un-calibrated NRG sensors were employed (exception Constanta port: The anemometers are for calibration at DEWI in Germany). In many earlier projects these sensors have been proven to be reliable. Additionally, inter-comparisons between sensors were possible thanks to high redundancy in the measurements. However, it would be possible to further reduce uncertainties by using calibrated sensors. This issue has already been taken into consideration, and after the act of sabotage on some masts in August 2007, the sensors were replaced by calibrated instruments. Also all new towers which have been erected in the area as well as the towers still to be installed will be equipped with calibrated sensors.

The present report only considers four measurement masts with a data availability of almost one year and therefore is preliminary. More measurement masts have been installed in the course of the last year and their data will be available for the next report. For example, the mast of Ramnicu will provide a climatology measured within the model boundaries for wind modeling, instead of having to rely on a climatology transferred from another area.

The NCAR/NCEP reanalysis data proved to be a suitable tool to establish long term climatologies for the region of northern Dobrogea, especially as any data from long term meteorological measurements are lacking.

Power production calculations.

The wind resource files of the modeled areas were used to calculate potential power productions of the planned wind parks with WindPRO. Summarized, the yield of the planned wind parks show amounts for NEH (net equivalent yearly hours) being higher than 2.600 h/y (P50 with 10% reduction after park efficiency).

According to IEC 61400-1 Standard (third edition 2005 - 08, pp 22), we have determined the wind turbine classes, which are suitable for each area.

Table 6 contains the calculated parameters at a hub height of 100 m for four measurement sites and the according wind turbine classes, where:

− v_{avg} 100 m [m/s]: mean wind speed at 100 m calculated with WindSim;
− v_{ref} [m/s]: reference wind speed average over 10 min (5 x v_{avg});
− I_{ref} [-]: expected value of turbulence intensity at 15 m/s.

Table 6

Wind turbine classes for Sacele East, Sacele West, Mihai Viteazu and Istria.

Measurement site	v_{avg} 100 m [m/s]	v_{ref} [m/s]	I_{ref} [-]	Wind turbine class
Sacele East	7,49	37,45	0,08	III C
Sacele West	7,75	38,75	0,09	II C
Mihai Viteazu	7,92	39,60	0,07	II C
Istria	7,89	39,45	0,07	II C

Since no turbulence data is available at hub height for the measurement sites, the turbulence has been calculated with data measured at 40 m. Turbulence intensity usually decreases with the height.

R E F E R E N C E S

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