WindSim® Computational Flow Dynamics Model Testing Using Databases from Two Wind Measurement Stations

Đorđe Klisić, Miodrag Zlatanović, and Ilija Radovanović

***Abstract*—Data gathered for the last several years from the two wind stations, located at the Šušara fields, was used to create local wind climate and meteorological parameter database. Extrapolation of the values contained in the database to an area of several square kilometers in the vicinity of the measurement stations, and to a height corresponding to technical properties of wind turbines, serves as a tool for planning future wind farms. While predicting wind resources, some uncertainties can occur which are usually related to measured data quality and reliability of extrapolation procedure. In case of hilly terrains with complex spatial configuration, reliability of the wind resources prediction is directly dependent to applied model of air mass movement dynamics. Focus of this paper was testing of the Computational Flow Dynamics (CDF) model implemented in the WindSim® software package. Testing was performed by comparing values of the measured and simulated mean wind speed at 30m. By varying and correcting the boundary conditions it was shown that applied model was able to predict mean wind speed value of one station while using the mean wind speed value of the second wind station as input information in the simulation, with an error comparable to measurement uncertainty. Simulation of air mass movement gave an insight to a wind speed fields at 30m for a spring – summer period. These results are important for the future wind exploitation in Serbia, and can provide better analysis of the climate conditions at the agricultural and vineyard area of Šušara fields.**

***Index Terms*—CFD model testing, wind fields over rough terrains, wind resource prediction, WindSim® simulation.**

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I. Introduction

Extensive exploitation of fossil fuels during the last century and the increasing emission of green house gasses led to significant upgrowth of the global mean temperature. In comparison, today global mean temperature is at least 1 ºC higher than it was at the beginning of the last century, and according to some models, we will have to prepare for a very grim future. These models estimate, that if the humanity keeps this level of industrial growth and green house gasses emission, we can expect the increase of the mean global temperature to be as high as 6.4 ºC at the end of the 21th century [1]. The consequences of such a radical global warming effect will be devastating, and it is doubtful if the planet could overcome this degree of human negligence. Renewable energy resources, such as wind power, hydropower, tidal forces, geothermal energy, are offering solution for this eminent threat to our planet. Many countries all over the world are embracing and developing technologies related to renewable energy sources, with wind power at the first place. It's estimated that today energy production from wind power participate in the global energy production with 2.5%, [2] and that some countries such as Denmark, Portugal and Spain have about 15% - 20% of stationary electricity production from wind [2].

Serbia, on its path to become EU member, is planning to incorporate in its energy production renewable energy recourses, predominantly by introducing wind power and expanding hydropower capacities. At this moment, Serbia's energy production from renewable energy resources is around 6%, mainly due to hydropower plants [3]. Plan is for the wind power to account in for 87 MW of installed power and 100GWh of produced energy in 2012 [4].

According to study made in 2002 [5] it was shown that Serbia's capacity for wind power installment is 1300 MW, which is around 15% of total power production in Serbia. Studies [5]–[8], were made during the last decade with a goal to map wind resources in Serbia, and create map of the average wind speed over the territory of Serbia. Conclusion of these studies is that the wind speed is grates in Southern Banat region, and Vršac's mountains region, and that these two regions have the biggest wind potential in the country. Map of the average wind speed over the territory of Serbia is presented in Fig. 1.

Computational Flow Dynamics (CFD) is a numerical model for solving fluid dynamics equations. Model implemented in software package WindSim® is based on solving simplified Navier – Stokes equations or RANS (Reynolds-Averaged Navier–Stokes). RANS are time-averaged equations of motion for fluid flow. The main idea behind these equations is Reynolds decomposition, whereby an instantaneous quantity is decomposed into its time-averaged and fluctuating quantities. These equations can be used with approximations based on knowledge of the properties of flow turbulence to give approximate time-averaged solutions to the Navier–Stokes equations. In general this means that the non-linear part of these equations is transformed to be linear. Downside of this approximation is a significant influence on the results and its precision [9], [10].

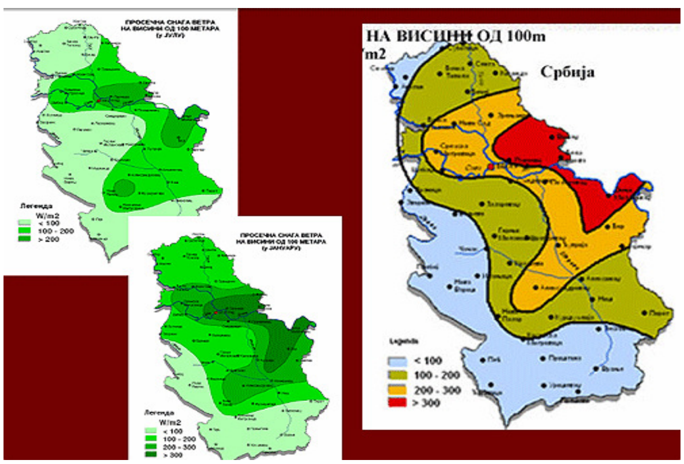

Fig. 1. Wind speed map at 100m over the territory of the Republic of Serbia. (On the left side distribution for winter and summer period, on the right side distribution for the whole year)[7].

When an air mass is traveling uphill, one of its parts is going to continue its movement in the same direction, following the mountain side, and the other part will usually separate from the main flow and start falling back to the surface in a circular path if the side is too steep (inclination greater than 20º). Also, when an air mass hits side of a hill or mountain, turbulent motion occurs as well. These two effects cannot be described with the Linear Flow Model, and thus many software packages using LFM cannot account for these effects. Even in case of hill with sides not steep enough to induce flow separation, wind speed prediction will deviate from measured value significantly when using LFM instead of CFD. Some software packages introduced methods for overcoming these limitations. E.g. WAsP, one of the most commercially used wind prediction software packages, tried to bypass this problem [11] by introducing ruggedness index (RIX) [12], [13]. RIX is good solution that improves precision of the predicted results significantly over the complex terrains. Still, CFD method is more reliable and robust in case of flow split and turbulences, since it can account for these two effects directly, without additional parameters or factors in the simulation. Flow separation, turbulences, and air mass flow over rugged terrain is illustrated in Fig. 2.

Wind speed simulation over some particular area is defined by a proper selection of boundary conditions at the borders of the area of interest and the height of the geostrophic wind above the surface. Boundary conditions considered by WindSim® software package are:

- Height at which the wind speed is considered to be constant
- Value of the speed at that height
- Boundary condition at top of the boundary level

The last parameter is related to terrain complexity. There are two selections for this parameter: fixed pressure, and non-frictional wall. First selection is better in case of hilly or mountain terrains and the second one is more efficient while predicting wind speeds over the fields, planes and grasslands. [14] Since the terrain at the "Šušara fields" is situated on the cultivated sand dyne and it's mostly hilly, lacking any flat surface, better choice for this parameter was fixed pressure approximation.

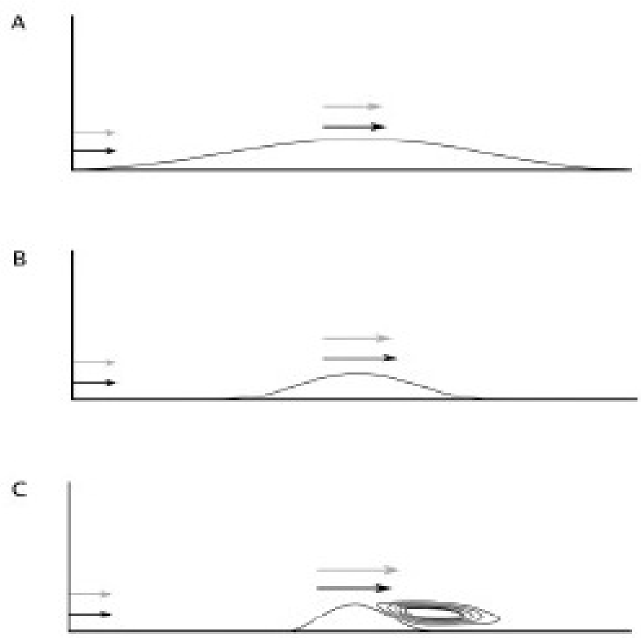

Fig. 2. Air mass flow in case of A) slightly rugged terrain, B) medium rugged terrain, C) highly rugged terrain (picture taken from [10]).

Data about boundary conditions can be obtained from the nearest meteorological measurements stations of the official institutions. Since the "Šušara fields" is a very remote area, far away from any official meteorological station (the nearest one is 30 km far and it's located in the town of Banatski Karlovci), and due to its complex orography, it wasn't any competent enough available data to be used in the simulation. This is why it was necessary to find valid boundary conditions values using some other method.

Testing of the WindSim CFD model was performed by comparing measurement results of the wind characteristics gathered from two measurement stations located at Šušara fields with the wind speed simulation results provided by the software package. Applied model for simulation confirmation and determination of boundary conditions is used as a starting verification of the model competence [15], [16]. Variation of different values of the boundary conditions is used to project and predict expected wind field raster of the second measurement mast at location B, using wind speed data from the first measurement mast at location A. If the model calculates satisfying values while predicting A on B, next step is to perform same operation, only in opposite direction, so one can get confirmation that the model will make good prediction in case of mast B being used to calculate wind field raster at location A. If the test in both directions are not contradictive with the measured values and deviate from the measured data within defined values, it can be considered that the model can be applied for an air mass movement simulation over the specified location, and that the simulation results are valid. 2D wind speed raster at 30 m height above the ground level at the chosen location will be presented in the paper.

II. Location of Measurement Station

Based on the wind speed estimation studies, Šušara fields locality is situated in the area with the greatest wind potential in South-East (SE) Banat. This locality represents a unique geo-morphological configuration shaped in a form of a 10km long and 500 m wide cultivated sand dune. This sand dune reaches heights from 40 to 100 m above the surrounding plains. It's situated at the northern border of the Special Nature Reserve (SNR) "Deliblato Sands". Because of its geo-morphological origin, as a relict of a former Pannonian sea, wind had great influence on its creation. Since the dominant wind over this locality is SE wind, also known as "Košava", thus, this sand dune has the same orientation as the dominant wind that shaped it for several millennia. Terrain configuration and orientation is presented in the Fig. 3.

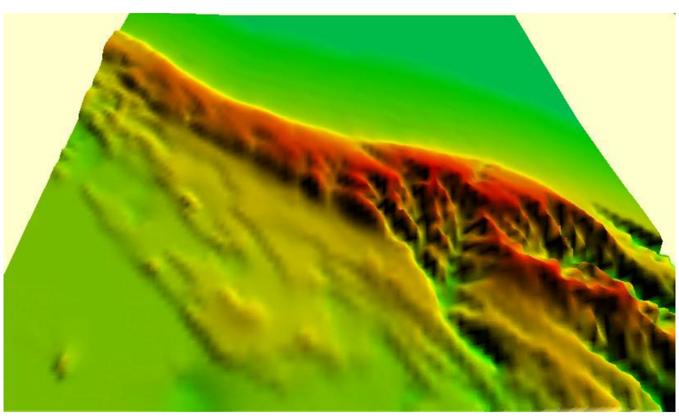

Fig. 3. Orography of Šušara fields locality.

Local inhabitants, living in the villages in the vicinity of Šušara fields, have century long tradition of wind power utilization. During the last years of the 19th century, first wind mill was constructed in the village of Šušara, 1.5 km south from the Šušara fields locality, with the purpose of mechanical propulsion of the local water station and mechanical workshop. These facts indicate that there is a significant wind potential, since the villagers were able to utilize it with great success more than hundred years ago.

Study of the climate conditions over selected locality was performed by utilization of two specialized measurement stations for gathering and primary processing of the meteorological data. Measurement masts are 50 m high. (Fig. 4) Anemometers are installed at 30, 40, and 50 m, and the corresponding wind vanes are installed at heights of 30 and 50 m. Location of the first measurement mast, marked as A, is on the SE side of the locality, situated on the top of the prominent hill, with the UTM coordinates 021.188 °E 44.939 °N (highest point of the Zagajica hills formation). On the other hand, second mast, marked as B, is installed at the location with the UTM coordinates 21.126 °E 44.959 °N, at the NW of the sand dune plateau. These two locations were selected, because location A potentially has the greatest wind potential, and the location B, on the other hand, has the lowest within the borders of the Šušara fields locality. Data gathered from these two stations at characteristic locations should enable more precise estimation of the local wind resource potential. Data gathering from the measurement stations, along with initial processing, are preface in the realization of the Šušara fields project, which should include up to 60 MW of the installed power, according to the project plans and energy license [17].

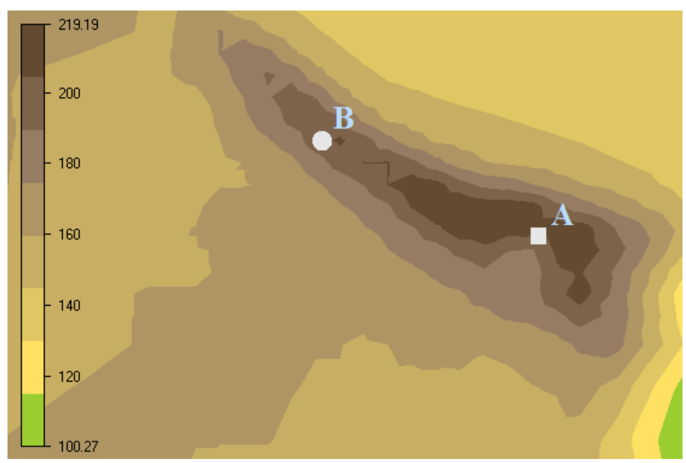

Fig. 4. Location of the measurement masts at the locality. Scale on the left represents height above the sea level in meters.

III. Sensors

Hardware used in this field study of the wind potential over the Šušara fileds locality consists of two 50 m tall measurement masts NRG TallTower. Both masts were equipped with four anemometers NRG #40C placed at heights of 30, 40, and 50 m. Along with the anemometers, two wind wanes NRG #200P were installed as well at heights of 30 and 50 m. Anemometers have 0.3 m/s offset and measurement error of ± 1%. For data transfer was used Symphonie iPackGPS (GSM/GPRS) data logger. Within the logger, data is being saved on a SD card with some basic encryption. Data written to SD card consists of 10 minute values of the measured quantities along with the calculated standard deviation measured every 2 second during the 10 minute interval. Since the locality is far from any kind of infrastructure, additional power supply was needed to provide necessary electricity. For that purpose, car battery was installed, along with 5 W solar panel.

IV. Model testing

In this paper, group of authors used WindSim® software package in combination with WAsP wind analysis software toll. WAsP 8.2 was predominantly used for primary statistical analysis of the data gathered from the measurement masts, and to derive wind roses from the data in the OWC module. On the other hand, WindSim® was used for extrapolation of meteorological data and for wind speed fields prediction over the locality. To perform this simulation, some additional data input was needed. Primarily, creation of a good orography 3D model of the locality was crucial. Next step was preparation of the roughness and obstacle maps. 3D map of the orography was prepared according to geographic maps with 1:25000 ratio in GlobalMaper and WAsP map editor. WindSim® model was tested with approximation that roughness of the forest present at the locality is uniform with the length z0=0.03 m.

WindSim® is software package for wind data analysis. Its GUI has a step-by-step design, and consists of several modules. First step is to define density of the surface grid, so the region of interest (defined by the location of two measurement masts) has bigger resolution. Before that, basic input data such as orography map and statistically processed wind databases were prepared in WAsP and its modules. Next step in WindSim® GUI is sector analysis and proper selection of the boundary conditions for CFD simulation. Comparison of simulated and real data served as a control if adequate boundary conditions were selected. Thus the best, and the easies, but more time consuming method for finding proper boundary conditions was brute force algorithm. First simulation goal was to find adequate boundary condition parameters that will give results similar to measured at location B, using the data from location A. When the proper set of boundary condition parameters for this case was found, another simulation was performed, but in opposite direction. These two steps were repeated until the difference between measured and simulated data was negligible. Local characteristics, such as orography, terrain roughness, and obstacles have great influence on wind characteristics at lower heights, while at greater heights are becoming insignificant, since the geostrophic characteristics will be dominant. For this paper, only available sets of data were ones from the 30 m height above the ground from both measurement masts.

V. Results

Data from measurement stations were gathered during the five year period, and for this paper authors had at their disposal data for the three month period from spring to summer 2010, so that the estimated roughness values correspond to the vegetation period. Data was first processed in OWC wizard (module of WAsP wind assessment tool). Results were wind roses for both masts. Using these wind roses, mean wind speed for the three month period at 30 m was predicted. For the masts A and B this speeds were 4.96 m/s and 4.70 m/s respectively. Also, they were used as a referent measured values that will be compared with the simulated wind roses from a WindSim® simulation (Fig. 5).

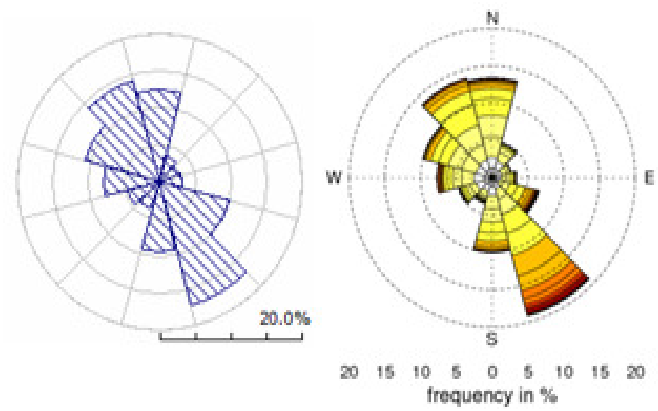

Fig. 5. Wind rose for the mast A calculated in OWC wizard (left) and wind rose of transfer climatology at the location of the mast A as a simulation result in WindSim (right).

Simulation testing was performed by constantly changing values of the boundary conditions parameters. Inadequate selection of boundary conditions parameters led to incorrect predictions of wind fields over the locality. E.g., if the selected maximum height of the simulation is too high, simulation will not be able to account terrain effects on the wind fields, and if the maximum height is too low, small changes in the boundary conditions will produce significant fluctuations in the resulting find fields. It was noticed that in some cases measured and predicted wind roses were almost the same, which is the proof that simulation didn't managed to include terrain effects because of the inappropriate boundary conditions (Fig. 6).

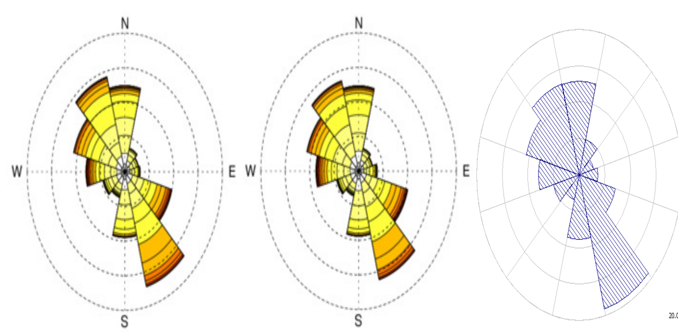

Fig. 6. Wind rose of the measured set of data from the mast A (left), wind rose as a result of simulation at location B using data from A (middle), Wind rose of the measured data form mast B (right).

Also, this will have influence on the wind speed fields prediction as well. Results presented in Fig. 7 shows how inadequate parameters of the simulation will produce wind map that will have highest wind speed values even at the location of the mast B which has the lowest wind speeds at Šušara fileds locality.

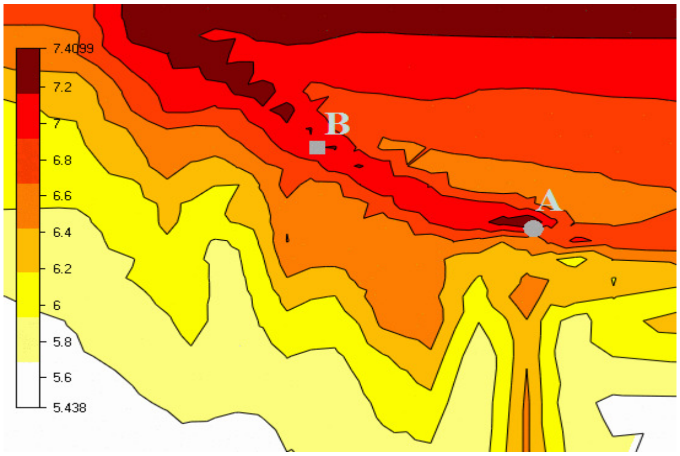

Fig. 7. Wind filed prediction at 30m, using inadequate boundary conditions. As a result wind fields with the grates energy potential can be found near locality B as well, which is contradictory to measured data.

After many attempts, proper set parameters was found providing prediction error of 1-2 % for the mean wind speed during the period of measurement while predicting climatology on second site using the data from the first site. This means that mean wind speed prediction error is 0.05-0.11 m/s and it is comparable to anemometers' measurement error which is ± 1 %. Results of a mean wind speed value prediction during the period of measurement are given in Table I.

TABLE I
MEAN WIND SPEEDS AT 30 M FOR THE MUSTS A AND B (MAIN DIAGONAL OF THE TABLE) AND MODEL PREDICTIONS FOR THE CASES *A→B* AND *B→A* RESPECTIVELY (OTHER DIAGONAL)

MAST AND ITS COORDINATES	**MAST A (30 m)** x=514812.6 m y=4976275 m	**MAST B (30 m)** x=509947 m y=4978416 m
MAST A (30 m) x=514812.6 m y=4976275 m	**4.96 m/s**	**5.07 m/s**
MAST B (30 m) x=509947 m y=4978416 m	**4.65 m/s**	**4.70 m/s**

This type of testing is used for the first approximation of the model certainty. Based on the similarity of measured and simulated wind roses, it can be assumed that the used fluid dynamics model is satisfying, so the right set of the boundary condition parameters can be found. Simulation using these parameters will make insignificant error, comparable to instrument measurement error, while predicting mean wind speeds at 30 m. Height profile was not part of this study, since authors only had available wind speed data at 30 m, so the model of local atmospheric stratification was not verified.

Using proper set of boundary conditions parameters, simulation calculated wind speed raster over the Šušara fields locality. Fig. 8 illustrates areas with the highest wind speed at the given height. These areas can be considered as the potential candidate for installation of the wind turbine of the same or similar height.

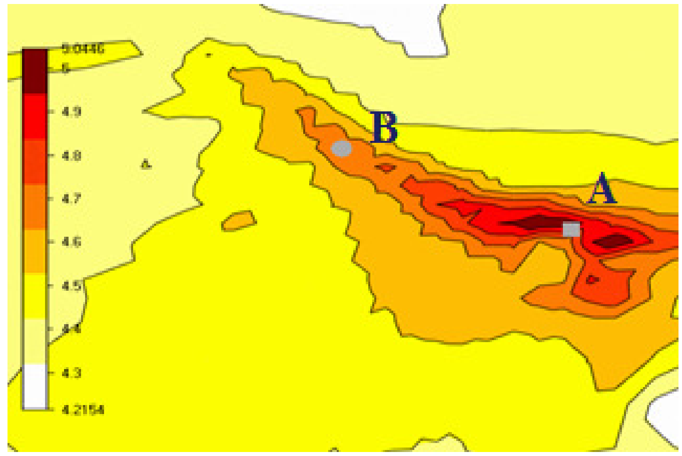

Fig. 8. Wind speed prediction over the Šušara fileds locality at 30m above the ground. Area around the mast A has the grates wind potential, while the area around mast B has the lowest.

Area of the Zagajica hills (location of the mast A) has the greatest wind potential within the borders of the Šušara fields locality. On the other hand, location of the second mast (mast B) is less windy because of the influence of the local orography. Wind speed decreasing trend from SE to NW is evident, confirming "Košava" to be dominant wind here, which played an important role in the process of relief formation of this locality throughout millennia.

VI. CONCLUSION

Preliminary testing of the WindSim CFD model was performed using Šušara fields locality as an example. Since the locality has areas of complex orography and the linear fluid dynamic model would not be able provide good results, the CFD model was tested. Mean wind speed from at the location of two measurement masts during the period data gathering was used as a comparison parameter for measured and simulated data. Difference between transfer climatology derived from calculated and simulated data at 30 m above the locality of Šušara fields was calculated by varying boundary conditions and simulation parameters, and it was within 2% corresponding to measurement error of the sensors. Due to a insufficient data about the stratification of atmosphere at the locality, brute force algorithm was used to find a proper set of boundary conditions and simulation parameters. Results confirm that the CFD model, and the WindSim software using it, is excellent choice of software tool for wind fields prediction for Šušara fields locality at 30 m above the ground. Calculations showed that the measurement masts are approximately situated at locations with highest and lowest wind potential. These results are important for future wind power harvesting and climatology conditions analysis over the Šušara fields locality. Further model analysis will comprise of sector testing, and climatology extrapolation to different heights.

REFERENCES

[1] IPCC (2007-05-04). "Summary for Policymakers" (PDF). ClimateChange 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Avilable: http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf. Jul 2009.

[2] World Wind Energy Report 2010, World Wind Energy Association. February 2011.

[3] Đereg N., Kalmar Krnajski Jović Z., Apostol I., "Renewable energy resources in Serbia, recommendations, potentials, criteria", Center of ecology and sustainable development, December 2008.

[4] Tešić M., Filipović D., "Strategy realization program for development of energetic of republic of Serbia in AP Vojvodina for 2007- 2012 period", Executive council of AP Vojvodina, Provincial Secretariat for Energy and Mineral Resources, April 2007.

[5] R. Putnik et. al., "Possibilities of wind energy utilization for electric energy production – case study", Electric Power Industry of Serbia, Belgrade, 2002.

[6] Case study of energy potential of Serbia for solar radiation and wind power utilization. Study EE704-1052A, Center for multidisciplinary studies. 2004.

[7] Katić V. Ćosić I., "Wind atlas of AP Vojvodina – case study", Faculty of technical science, Novi sad, December 2008.

[8] Zlatanović M., "The use of wind energy in Serbia –Natural conditions and practical policy", Jefferson Institute, December 2009. Available: http://www.jeffersoninst.org/

[9] Gravdahl A.R., "Meso Scale Modeling with a Reynolds Averaged Navier-Stokes Solver. Assessment of wind resources along the Norwegian coast." International Energy Agency Annex XI, Risø Denmark, October 1998.

[10] Milashuk S., W.A. Crane, "Wind speed prediction accuracy and expected errors of RANS equations in low relief inland terrain for wind resource assessment purposes", Environmental Modelling & Software 26,pp. 429 – 433, 2011.

[11] Bowen A. J.,Mortensen N. G., Exploring the limits of WAsP, "The wind atlas analysis and application program", paper O15.2, EU wind energy conference, May 1996.

[12] Mortensen N. G., Heathfield D. H., Myllerup L., Landberg L., Rathmann O., "Getting Started with WAsP 8" Risø National Laboratory, Roskilde, Risø-I-1950(ed.2)(EN), March 2004.

[13] Pianigiani M., "Comparison of Ansys CFX and WAsP for Sarfanngua ", Master Thesis, Technical University of Denmark, February 2009

[14] WindSim 5.0, *Getting started*, September 2010.

[15] Llombart, A., Mallet, A., Burillo, N., Alvarez, O., Talayero, A., „Influence of Orography on Wind Resource Assessment Programs", European wind energy conference, Milano, 2007.

[16] V. Riedel and F. Durante, "Harvest time in the mountains: round robin numerical flow simulation in wind energy", part 2, DEWI 32, pp. 12–26, 2008.

[17] Ministry of Mines and Energy, the list of issued permits for wind power energy. Available online: www.mem.gov.rs