# TIMOK REGION WIND ENERGY POTENTIALS

[1]P. Živković, [1]D. Petković, [1]M. Vukić, [1]J. Janevski, [2]M. Tomić, [3]D. Dimitrijević Jovanović

[1]*University of Niš, Faculty of Mechanical Engineering*
[2]*University of Novi Sad, Faculty of Technical Sciences*
[3]*Innovation Center of Advanced Technologies CNT*

## Introduction

Energy, especially electrical, is of vital importance in the world today. Many assesments of the fuel resources, mostly fossil, clearly marks the fact that this resources, especially for oil, are close to the end. The need for energy constantly rises, so introduction of new resources is inevitable. All these facts points to the necessity of transition to the sustainable development, especially to the usage of renewable energy sources. Wind energy clearly takes its place, considering its large potentials, purity and availability. The present constrains are mostly of financial nature.

The most important task is the *siting* of wind turbines (obtaining the best possible locations for installing of the turbines, considering the possibility for energy production and minimization of losses). For that purpose, the wind atlas method is developed, which became easy for use with the fast development of computers. Position of wind turbine is in strong correlation with energy production. According to the previous research [4], linear models can't estimate correctly the wind energy potentials in the terrain where the ruggedness index (index that represents the terrain slope value) exceeds 0.3. In such a case, using full CFD models, followed by experimental validation is necessary.

## Mathematical model

CFD models are more precise, but they need much more computational time. Considering the need to obtain the results as soon as possible, the best micro models were extracted from the larger macro models using the fast linear software. Than the best wind turbine locations were obtained by using CFD software, either linear as WasP [1], or the full nonlinear WindSim [2].

In this paper combination of a linear (WAsP [1]) and full nonlinear model (WindSim, a module in PHOENICS code [4]) was used.

### *A. Linear model*

Linear model is expressed by the:

*continuity equation:*

$$\frac{\partial}{\partial x_i}(\rho U_i)=0, \tag{1}$$

*logaritmic vertical wind profile:*

$$U_z=\frac{U_*}{\kappa}\left(\ln\frac{z}{z_0}-\psi\right), \tag{2}$$

*Weibull distribution equations:*

$$f(U)=\frac{k}{A}\left(\frac{U}{A}\right)^{k-1}\exp\left[-\left(\frac{U}{A}\right)^{k}\right], \quad (3)$$

$$F(U)=\exp\left[-\left(\frac{U}{A}\right)^{k}\right], \quad (4)$$

Representative of the linear software packages is WAsP [1], [4]. It calculates the speed-up effects of the hills, taking into consideration the effect of redistribution of energy in the flow from the component in the flow direction into the vertical component.

*B. Nonlinear model*

Nonlinear model solves the full set of governing equations of steady fluid flow.

*continuity equation:*

$$\frac{\partial}{\partial x_i}(\rho U_i)=0, \quad (5)$$

*continuity equation:*

$$U_j\frac{\partial U_i}{\partial x_j}-\frac{\partial}{\partial x_j}\nu_{eff}\left(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_j}{\partial x_i}\right)=-\frac{1}{\rho}\frac{\partial P}{\partial x_i}, \quad (6)$$

*turbulence model equations:*

$$U_j\frac{\partial k}{\partial x_j}-\frac{\partial}{\partial x_j}\left[\left(\nu+\frac{\nu_T}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]=P_k-\varepsilon, \quad (7)$$

$$U_j\frac{\partial \varepsilon}{\partial x_j}-\frac{\partial}{\partial x_j}\left[\left(\nu+\frac{\nu_T}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]=\frac{\varepsilon}{k}\left(C_{\varepsilon 1}P_k-C_{\varepsilon 2}\varepsilon\right), \quad (8)$$

where:

$$P_k=\nu_T\left(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_i}{\partial x_j} \quad (9)$$

$$\nu_{eff}=\nu+\nu_T \quad (10)$$

$$\nu_T=C_\mu k^2/\varepsilon \quad (11)$$

The modified set of model coefficients is:

$C_\mu=0.0324$, $C_{\varepsilon 1}=1.44$, $C_{\varepsilon 2}=1.92$, $\sigma_k=1.0$, $\sigma_\varepsilon=1.85$

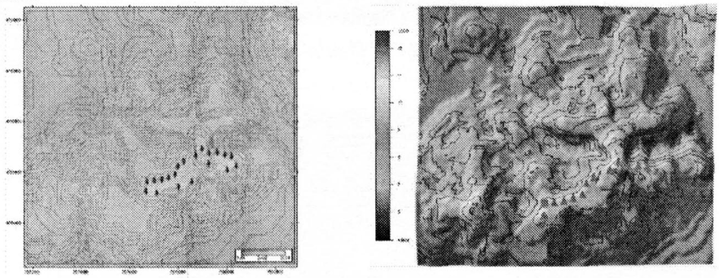
The set of these nonlinear partial differential equations is solved by WindSim [2] software package.

**Combined methodology**

The differences in wind energy estimations while using these different approaches are considerable. Many investigations were done on this subject, dealing with different aspects of the software operation.

Test model of Selicevica mountain [3] was choosen by its adequate orography, as can be seen in Figure 1. It was shown that the WAsP predictions are about 30% larger than WindSim ones, due to neglecting of the second-order terms in the momentum equation.

For obtaining of the results the nesting technique is used. Simulations were done for the Enercon E82 wind turbine. It is very appropriate to use WAsP as the initial software on mezzo level estimations, and WindSim for more precise micro level estimations, as the computational time for WAsP is about 20 times less than for WindSim.



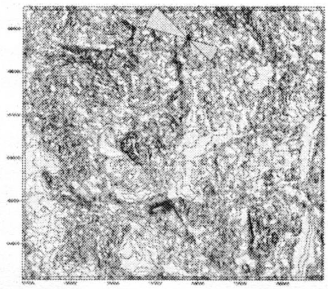
*Pic. 1. Mean wind speed fields obtained by simulations in WAsP (left) and WindSim (right)*

**Rtanj and Tupižnica wind potentials**

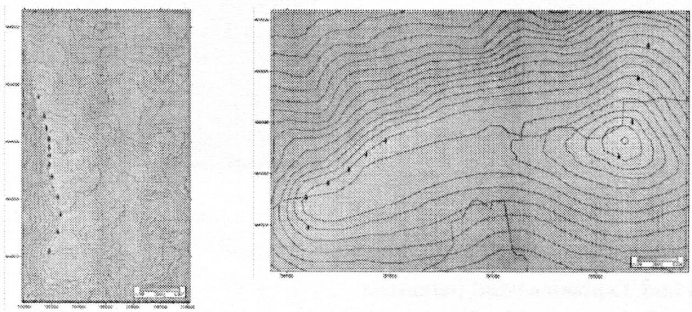
Scope of this paper is Central Timok region. The Rtanj and Tupižnica mountains, as the most prominent in this region, are situated in the Eastern Serbia, between the towns of Knjaževac, Sokobanja and Boljevac. This is southeastern border of the Velika Morava river valley, but it streaches to the Timok valley, so the winds are similar to the ones for Balkan mountain, which is about 25km to the east. Such configuration of the terrain creates somewhat channel flow, which is obvious in the one dominant wind direction, of very stable winds. The plan of developing the ski center Babin Zub, and the relatively less developped electrical network in the surrounding settlements, makes this location even more desirable.

The potentials are estimated for turbine Enercon E-82, with unit power of 2MW. Considered mezzo models were choosen by former simulation on the bigger model, from which, using the nesting technique, named micro models are obtained.

For the turbine siting the method of wake loss minimization and maximal annual energy production was used. Also, the recommendations about distance between wind turbines for the siting were as follows: in the wind direction minimally 7D (D – rotor diameter) and in the normal direction 4D. The same locations were used fo all three turbine types.



*Pic.2. Rtanj and Tupižnica map with wind rose*



*Pic. 3. Rtanj (left) and Tupižnica (right) AEP fields*

On the basis of the data about the terrain slopes and roughnesses, obtained from the digital map, and the data about the wind speed and direction represented with the long term wind rose on the site of the main meteorological station Crni Vrh, the simulations were performed in both software packages: WAsP and WindSim. The result shown in the Table 1 are the fields of possible energy production and terrain slopes.

*Table 1. Summarized results for all wind farms*

| Location | AEP [GWh] | Turbine № | capacity factor [%] |
|---|---|---|---|
| Rtanj | 51.2247 | 12 | 29.24 |
| Tupižnica | 25.116965 | 10 | 23.89 |

**Economical analysis**

Economical analysis is one of the most important parts of every project. Renewable energy, including wind energy, is not an exception. Having in mind current prices of wind turbines, state of the global and local financial markets, and the fact that the local infrastructure is not very developed, preliminary financial analysis was done. The estimated financial indicators (Rate of income ROI, Simple payback time SPB, Net present value NPV, Internal rentability rate IRR, Dynamic payback time DPB, Benefit/cost ratio B/C and Lifelong cost savings LCS) are shown in the following Table 2.

Using above mentioned financial indicators, it was calculated that annual income of the wind farms could be about 1.89 milion EUR for Rtanj and 2.55 milion EUR for Tupižnica site, annually.

**Conclusions**

The Timok region around Rtanj and Tupižnica mountains is scarcely populated area, and as such is in great need of investment. Wind resources are very desirable, as well as relatively easy reachable. Nearness of the Danube river shows possibility for relatively easy transport of the turbines almost to the site by water.

Dissadvantage is that this area is prone to frosting, so the blades should be heated in winter, which reduces the amount of energy produced, and increases the costs.

*Table 2. Financial indicators*

| FINANCIAL INDICATORS | | | |
|---|---|---|---|
| Site | Rtanj | Tupižnica | |
| ROI | 3.64 | 2.73 | [%] |
| SPB | 17.87 | 11.27 | [yr] |
| NPV | 73.51 | 59.76 | [mil€] |
| IRR | 0.00 | 0.00 | [%] |
| DPB | 0.00 | 0.00 | [yr] |
| B/C | 88.14 | 78.51 | [-] |
| LCS | 4.13 | 6.584 | [mil€/yr] |

**Acknowledgments**

This paper is concerned by the National Program of Energy Efficiency, project number: TR33036, funded by the Government of Republic of Serbia.

***References:***

1. WAsP (Wind Atlas Analysis and Application Program), Wind Energy Department at Risø National Laboratory, Denmark

2. WindSim - Delft University, Denmark, available as module of PHOENICS software package

3. P. Živković, *Wind energy estimations in terrain with complex orography - comparative methodology analysis*, master thesis, Faculty of Mechanical engineering, Niš, 2006

4. P. Živković, G. Ilić, Ž. Stevanović, *Wind Power Assessment in Complex Terrains of Serbia*, Proceedings of the 21st International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, Cracow-Gliwice, Poland, June 24-27, 2008, pp 1141-1148, ISBN 978-83-922381-4-0.

5. P. Živković, M. Tomić, D. Dimitrijević, I. Kecman, M. Dobrnjac, *Influence of the changing local climate on wind potentials of mount Kopaonik*, Facta Universitatis. Series: Mechanical Engineering, (2017), Vol. 15, No. 3, pp. 507-516.