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[1.] Predrag ŽIVKOVIĆ, [2.] Mladen TOMIĆ, [3.] Dušan PETKOVIĆ,
[4.] Ivan ĆIRIĆ, [5.] Mirko DOBRNJAC, [6.] Velimir STEFANOVIĆ,
[7.] Žana STEVANOVIĆ

WIND ENERGY POTENTIALS OF VLASINA REGION

[1,3,4,6.] University of Niš, Faculty of Mechanic Engineering, Niš, SERBIA
[2.] The School of Higher Technical Professional Education, Niš, SERBIA
[5.] University of Banjaluka, Faculty of Mechanical Engineering, Banjaluka, BOSNIA & HERZEGOVINA
[7.] Belgrade, Institute for nuclear sciences Vinča, SERBIA

Abstract: *Obtaining of all acceptable locations is one of the main tasks for siting of wind turbines. The main goal of this paper was to estimate wind potentials in Vlasina region, mainly on Strešer and Besna Kobila mountains. Finally, 231 locations are accepted, which covers the most of the area of the south of Vlasina lake, until the borders with FYR Macedonia and Bulgaria, respectively. The estimations were obtained using the WAsP simulation software. Final results are compared by means of the quality and quantity of the wind data and capacity factor. Finally, the economical analysis of the acceptabillity of the installing of wind turbines was done. This paper is concerned by the National Program of Energy Efficiency, project number: TR33036, funded by the Government of Republic of Serbia.*
Keywords: *wind power assesment, complex terrain, CFD, WAsP, WindSim*

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, in the order of two or even three degrees of magnitude. Considering the need to obtain the results as soon as possible, the best micro models were extracted from the larger macro models (well known nesting technique) using the fast linear software [4]. Then the best wind turbine locations were obtained by using CFD software.

In this paper combination of a linear (WAsP [1]) and full nonlinear model (WindSim, a module in PHOENICS code [2]) is used.

Linear model

Linear model is expressed by:

- *continuity equation:*

$$\frac{\partial}{\partial x_i}\left(\rho U_i\right)=0$$

- *logaritmic vertical wind profile:*

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

- *Weibull distribution equations:*

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

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

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.

Nonlinear model

Nonlinear model solves the full set of governing equations of steady fluid flow. The governing equations have the following form:

- *continuity equation:*

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

- *momentum equations:*

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

- *turbulence model equations:*

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

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

where

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

$$\nu_{eff}=\nu+\nu_T;\ \nu_T=C_\mu k^2/\varepsilon$$

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

Test case

The differences in wind energy estimations while using these linear or full CFD software are considerable. Many investigations were done on this subject, dealing with different aspects of the software operation. Test model of Seličevica mountain [4] was choosed 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 [3], due to neglecting of the second-order terms in the momentum equation.

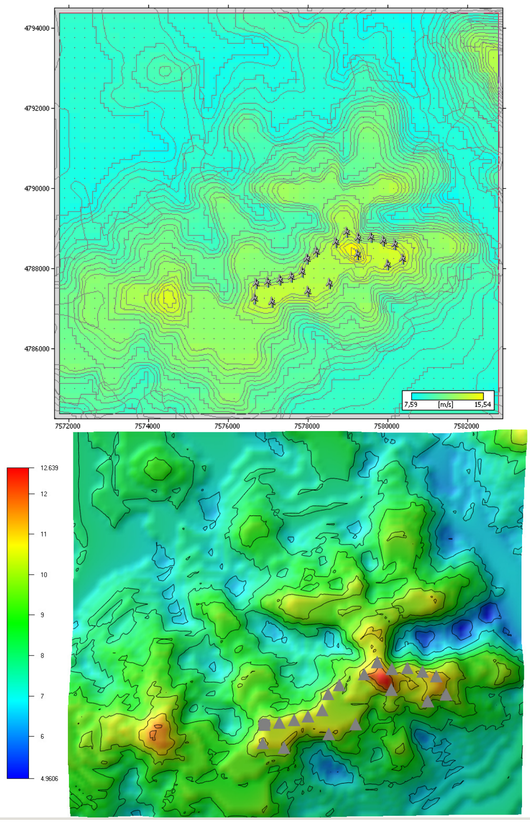

Figure 1. Mean wind speed fields simulated in WAsP (left) and WindSim (right)

For obtaining of the results the nesting technique is used. Simulations were done for the Enercon E48 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. This comined methodology had given very good results for a numer of sites.

VLASINA REGION WIND POTENTIALS

Scope of this paper is the Vlasina region, which is situated eastern of the South Morava river and southern of Suva Planina mountain, up to the borders with Bulgaria and Macedonia, respectively. The most promising locations are mountains Strešer and Besna Kobila, which dominates the Southeast of Serbia. This region, with the highest altitude of 1922m above sea level and relatively gentle slopes is very promising for wind energy. Another advantage is the existence of several hydro power plants, which allows combining wind and hydro energy, which gives possibility of energy storage.

Chosen wind turbine type is Enercon E-82, with unit power of 2MW. Considered mezzo model was *choosen by former simulation on the bigger model, from which, using the nesting technique, named mezzo model is 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.

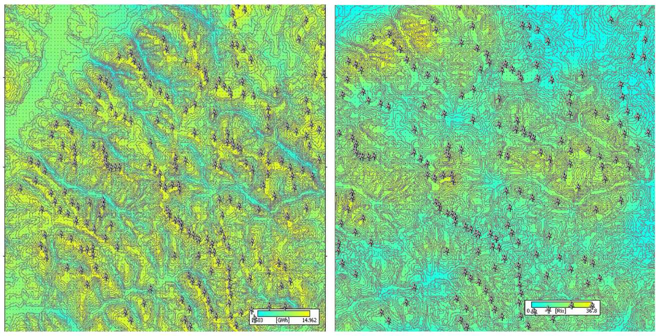

Figure 2. Annual energy production (left) and ruggedness index (right) fields

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 Vranje, the simulations were performed in both software packages: WAsP and WindSim. The result shown are the fields of possible energy production and terrain slopes.

Finally, 231 possible location were obtained through the simulations. The summary data are presented in the following table.

Table 1. Summary data for the Vlasina wind farm

Parameter	Total	Average	Minimum	Maximum
Gross AEP [GWh]	2979.609	13.011	8.290	15.168
Net AEP [GWh]	2966.845	12.956	8.242	15.147
Wake loss [%]	0.43	-	-	-

Expected capacity factor (expected ratio of possible energy production to the nominal production) is about 30.1%, which marks this location as highly desirable.

ECONOMICAL ANALYSIS

Economical analysis is one of the most important parts of every project. Renewable energy, including wind energy, is not an exeption. 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 developped, preliminary financial analysis was done. The initial assumptions are: the farm will operate for 25 years; initial investment is 924 million EUR; subventions will be 10%; annual discout rate will be 10%; annual inflation will be 7%; increase of the electricity price will be 12% per annum. Expected electricity price is 0.104EUR. The estimated financial indicators are shown in the following table.

Table 2. Financial indicators

FINANCIAL INDICATORS			
Rate of income (year 01)	ROI	240.06	[%]
Simple payback time	SPB	0.41	[year]
Net present value	NPV	57773754	[EUR]
Internal rentability rate	IRR	0.00	[%]
Dynamic payback time	DPB	0.01	[year]
Benefit/cost ratio	B/C	4611.03	[-]
Lifelong cost savings	LCS	6364823	[EUR/ year]

Using above mentioned financial indicators, it was calculated that annual income of the wind farm in Vlasina region could be about 202 million EUR. It shows that the project payback time is up to 5 years, which gives hope that such a project could be realized.

CONCLUSION

Wind energy is one of the fastest growing renewable energy resources. Most of the EU members are using it widely. Yet, the available usable locations are not limitless. This gives opportunity to the less developed countries to use the available funds, considering the plan of 20% of energy in Europe to be obtained from renewable sources.

Vlasina region is scarcely populated area, and as such is in great need of investment. Wind resources are very desirable, as well as the existence of Vlasina Lake, which can be used for *energy storage.*

Dissadvantage is that this area is highly used by migrating birds, so the environmental impact should be carefully estimated.

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