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WIND ENERGY IN JABLANICA-TOPLICA REGION OF SOUTH SERBIA

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Abstract: Obtaining of all acceptable locations is one of the main tasks for siting of wind turbines. Very thorough analyses are needed in order to ensure the finalization of the project. However, economic factors are usually very limiting. One of the possibilities to increase the efficiency of the wind farm is to reduce the transport loses, as well as the initial investment, by using produced energy as close to the production site as possible. This paper focuses on the possibilities of the Radan Mountain wind potentials usage in the nearby city of Leskovac, located between the Jablanica and Toplica regions of the Southern Serbia. The estimations were obtained using the WAsP simulation software. The results are compared by means of the quality and quantity of the wind data and capacity factor. Finally, the economic analysis of the acceptability 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 turbines, wind potentials, Radan Mountain, Southern Serbia, WAsP simulation software

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 such 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 [1,2,3], linear models can not 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. Even if all of the above mentioned is satisfied, there is possibility that the wind warm is not going to have the predicted outpun during the project lifetime, which is 25-30 years, which is about the same as the climatic periode, which lasts for 32 years.

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 model was extracted from the larger macro model using the fast linear software [4]. Then the best wind turbine locations were obtained by using CFD software [5]. In this paper combination of a linear and full nonlinear model is used.

— LINEAR MODEL

Linear model is expressed by the subsequent set of equations.

≡ Continuity equation

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

≡ Logaritmic vertical wind profile

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

≡ Weibull distribution equations

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

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

— NONLINEAR MODEL

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

≡ Continuity equation

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

≡ Momentum equations

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

≡ Turbulence model equations

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

$$U_j\frac{\partial \varepsilon}{\partial x_j}-\frac{\partial}{\partial x_j}\left[\left(\nu+\frac{\nu_T}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]=\frac{\varepsilon}{k}(C_{\varepsilon1}P_k-C_{\varepsilon2}\varepsilon) \qquad (8)$$

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

The set of the nonlinear partial differential equations is solved by the WindSim [5] software package.

COMBINED METHODOLOGY

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 model was extracted from the larger macro model.

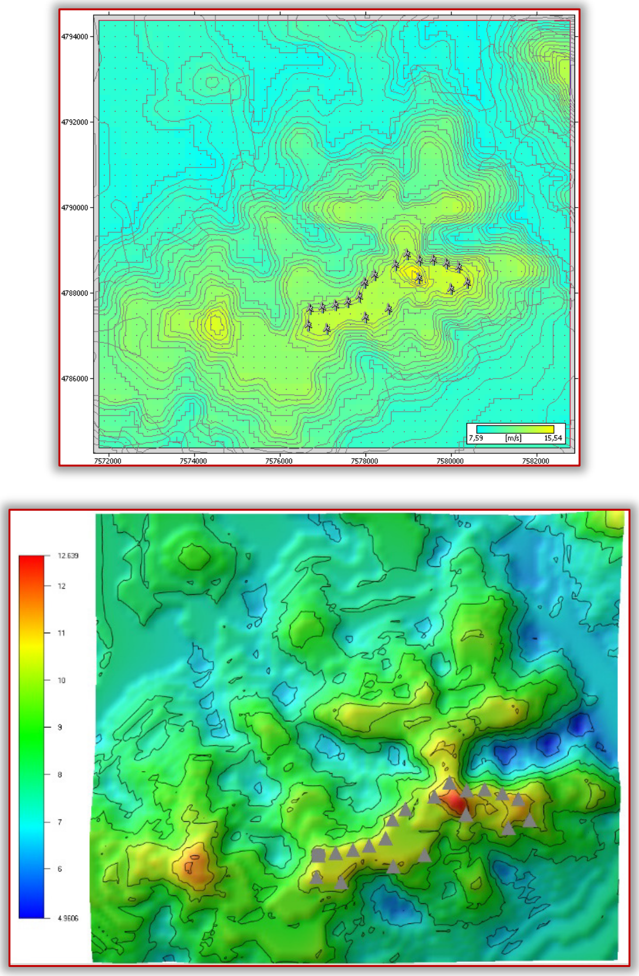

Figure 1. Mean wind speed fields obtained by simulations in WAsP (left) and WindSim (right)

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 Seličevica mountain [3] 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 [5] ones (estimated wind speed is in range 7.75-15.54m/s for WAsP, and 4.96-12.64m/s for WindSim), due to neglecting of the second-order terms in the momentum equation, i.e. (6).

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.

In the previous papers [6,7,8] results obtained by numerical simulation on over a dozen micro locations are presented. The considered locations mainly covers the mountinous regions of Southern and Eastern Serbia.

RADAN MOUNTAIN WIND POTENTIALS

This paper considers the wind potentials of the Toplica – Jablanica regions, bounded by the river Toplica valey from the north, river Jablanica valey from the south, river South Morava valey from the east and the slopes of the Kopaonik mountain from the west. This region area is about 6000 km^2. Characteristical of this region are all types of land by elevation – flatlands, hills and low mountain areas.

Highest ground is on the Radan mountain, with area of some 466 km^2, highest peak being Šopot with 1409 m asl. The insolation is also very pronounced from the south and east, towards Pusta Reka valey, so the oak forests can be found even at 900 m asl. Predominant wind direstion is north-northwest all year round, which is to be espected, as it is the Morava river valey direction. Nevertheless, the wind speed is moderate, as the moderate slopes of the Radan mountain does not give high speed-up effects, although there is no high vegetation at the summit.

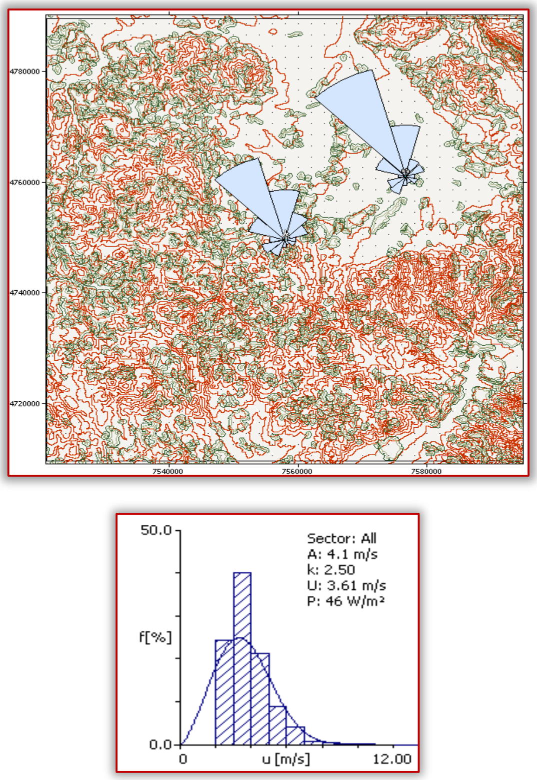

Figure 2. Macro model with wind roses (left) and Weibull distribution (right)

Chosen wind turbine type is Enercon E-48, with unit power of 800kW. Considered micro model was choosen by former simulation on the bigger model, from which, using the nesting technique, micro model for Radan wind farm 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.

After the simulation were done and the fields of annual energy production (AEP) and the ruggedness index (RIX) for the macro model, and the mean wind speed, power density and AEP fields with turbine dispositionfor the micro model are presented on the following figures.

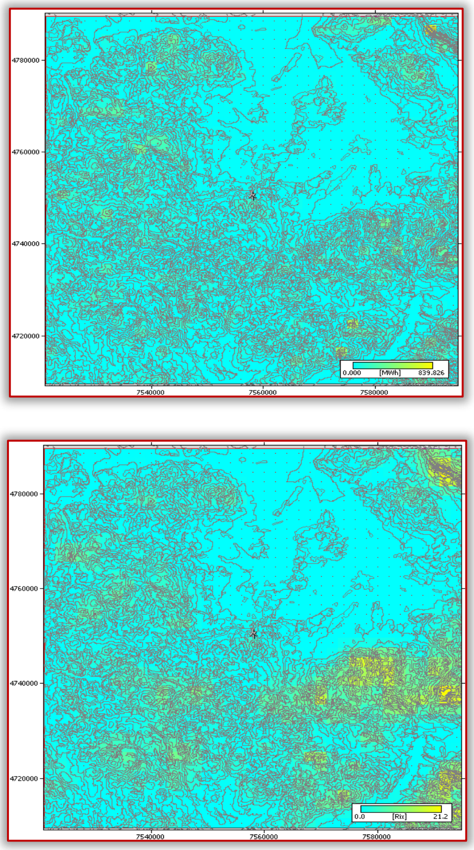

Figure 3. AEP field (left) and RIX field (right) for the macro model

On the basis of the data obtained by simulation, and the known turbine power, the capacity factor C_p can be calculated for the considered wind farm. The capacity factor is the ratio of the eral power output of a wind farm to its nominal output (if working on the full potential) for a period of time, for the case considered, annually. This can be presented in the form:

$$Cp = \frac{AEP \cdot 0{,}1178}{8760 \cdot Pt \cdot 1{,}3} \qquad (12)$$

where are: P_t installed power of the farm with 15 wind turbines Enercon E-48, 0.1178 is the percentage of accepted data (all the other can be considered as calm, i.e. <2m/s) and factor 1.3 is as the WasP software overprediction.

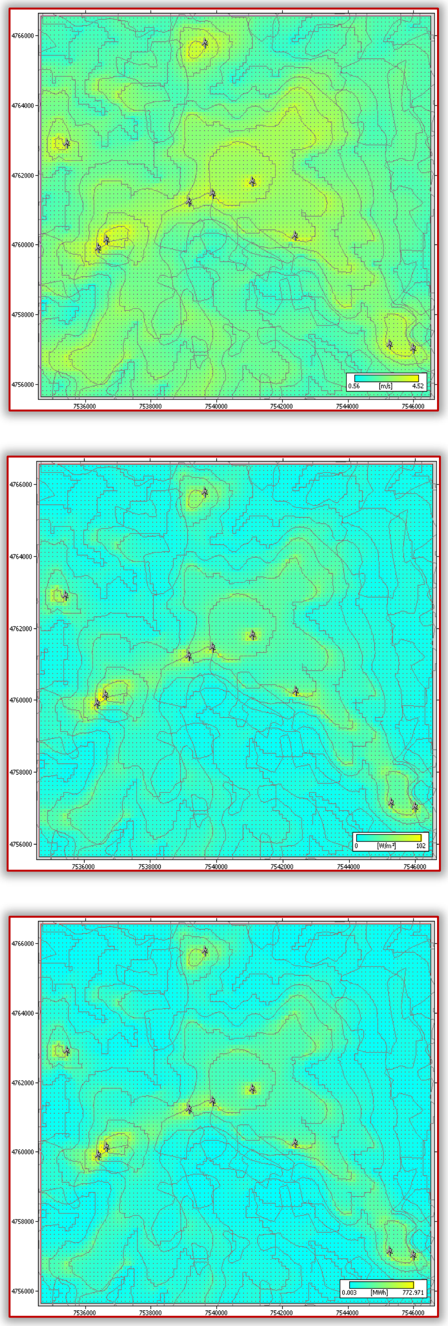

Figure 4. Mean wind speed (left), power density (middle) and AEP fields (right) for the micro model

Stable wind data were obtained from the main meteorological station Leskovac. As the turbine acceptable wind speed is in the range of 2÷25m/s, only 11.78% of the wind data are in the acceptable range. Considering this, as well as the overestimation by the used software, the capacity factor (ratio between possible AEP and max AEP) is calculated to be C_P=0.13. It is considered that the ecconomicaly acceptable locations are with C_P=0.25 or larger:

Table 1. Predicted values for the 10 turbine wind farm Radan

Parameter	Total	Average	Minimum	Maximum
Nett AEP [MWh]	6485.465	648.546	543.833	838.266
Gross AEP [MWh]	6497.657	649.766	544.543	842.152
Wake loss [%]	0.19	-	-	-

TECHNO-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 the 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 initial assumptions are: the farm will operate for 25 years; initial investment is 8 million EUR; subventions will be 10%; annual discount rate will be 10%; annual inflation will be 7%; increase of the electricity price will be 5% per annum. Expected electricity price is 0.104EUR. The estimated financial indicators are shown in the following table.

Table 2. Financial indicators for the 10 turbine wind farm Radan

Rate of income (year 01)	ROI	1.70	[%]
Simple payback time	SPB	13.21	[year]
Net present value	NPV	10.743	[M EUR]
Internal rentability rate	IRR	70.93	[%]
Dynamic payback time	DPB	2.30	[year]
Benefit/cost ratio	B/C	29.57	[-]
Lifelong cost savings	LCS	1.184	[M EUR/ year]

Using above mentioned financial indicators, it was calculated that annual income of the wind farm Radan could be about 0.65 million EUR. It shows that the project payback time is about 13 years, which is not economically acceptable at this moment. There is hope that with the trend of the reducing of initial investments, considering the vicinity of the important local centres of industry and commerce such as Niš and Leskovac and the accessibility of the location, one day such project could be finalized.

In order to improve the predictions in the presented research, validation of the data should be done by on-site measurements [9,10,11]. As the potentials are well below the acceptable margin of potentials (C_p~13% of the lower limit of 25%), there is possibility for combinig the system with solar or other types of RES [12,13], in order to increase the efficiency. Some new approaches to the problem of the wind farm production estimations can also be implemented [14].

CONCLUSIONS

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, in the scope of 20% of energy in Europe to be produced by renewable sources.

The estimated wind potentials are relatively low, with capacity factor being about half of the minimal (13 of 25%). Simply analyzed, this project is not profitable. From the other hand, there is hope of decreasing the initial investments, which would increase the profitability. There is also the easy accessibility of the location, as well as the vicinity of important local centers of Niš and Leskovac, which are always in need of more energy.

Acknowledgment

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Note

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