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Analysis of The Wind Energy Potential of The Czech Republic with Respect to its Integration into The Power System

Jaroslava Orságová[1)], Petr Toman[1)], Jiří Ptáček[2)], Petr Modlitba[2)]

[1)] Brno University of Technology, Faculty of Electrical engineering and Communication, Department of Electrical Power Engineering, Technicka 8, 616 00 Brno, Czech Republic, www.feec.vutbr.cz/UEEN

[2)] EGÚ Brno a. s., Hudcova 76a, 612 48 Brno, Czech Republic, www.egubrno.cz/

ABSTRACT

The paper deals with the analysis of the usable wind energy potential on the territory of the Czech Republic, performed within the frame of the study on connecting wind power plants to the distribution and transmission systems [1]. To assess the total energy potential of wind, the following method was used. First, the total area suitable for wind power development is quantified. Then, by applying the density of potential installed capacity in MW/km^2, the total potential installed capacity of wind power plants (WPP) on the territory of the Czech Republic is obtained.

Keywords: Distributed generation, wind power, land requirements, wind energy potential.

1 INTRODUCTION

The total area suitable for wind power development is found by the combination of the map of wind energy potential guaranteeing the profitable operation of WPP and the maps of areas where building WPPs is very complicated or impossible. The principal source material for the analysis is the wind map conceived by the Institute of Atmospheric Physics of the Czech Academy of Sciences *[Ústav fyziky atmosféry AV ČR]* [2] showing average wind speeds at 100 metres above the ground. Other maps conceived by various specialized institutions are used too. Those maps were obtained from open sources as well as from the database of the EGÚ Brno Company. All the maps were transformed to the same format and scale so that they can be compared and combined in *Mathematica* program. Thus only the areas suitable for wind power development can be extracted. The map resolution of 4026×2334 pixels is used: taking into account the size of Czech Republic 1 pixel corresponds to about 120 metres in reality.

In the second step, so-called unit area (area necessary for generating 1 MW in WPPs) is estimated. It represents the density of installed capacity and can be used for calculating the installed capacity of WPPs potentially connected to individual nodal areas of the distribution and transmission systems. The obtained potential of WPPs was then analysed in the study from the point of view of the transmission capacity of a given section of the network and the safety of its operation.

2 AREAS SUITABLE FOR WIND POWER DEVELOPMENT

The determination of areas suitable for wind power development is based on the requirement of the efficient exploitation of primary energy contents stipulated in the Regulation No. 475/2005 Coll., for the implementation of the Law on the Support of Exploitation of Renewable Energy Sources where it is stated that the yearly average wind speed at the height of the rotor of a proposed power plant should be at least 6 m/s. The wind map showing the distribution of wind speeds in m/s at 100 metres above the ground conceived by the Institute of Atmospheric Physics of the Czech Academy of Sciences is used (Fig. 1).

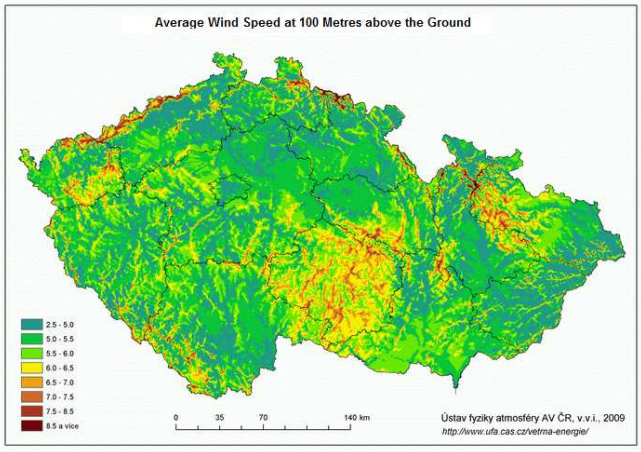

Fig. 1 Wind Map [2]

Applying the colour scale representing wind speeds, only the areas corresponding to the above-mentioned profitability criterion were separated. Then the territories where building WPPs is either completely excluded or very complicated, were eliminated.

Protected Landscape Areas [Chráněné krajinné oblasti] (CHKO) and National Parks [Národní parky] (NP) of the Czech Republic

It can be seen in Fig. 2 that the territories of 4 national parks and 25 protected landscape areas (in green) were eliminated from the map of areas with wind speeds exceeding 6 m/s at 100 metres above the ground. The list of national parks and protected landscape areas can be found in the Law

No. 114/1992 Coll., on the Protection of Nature and the Landscape.

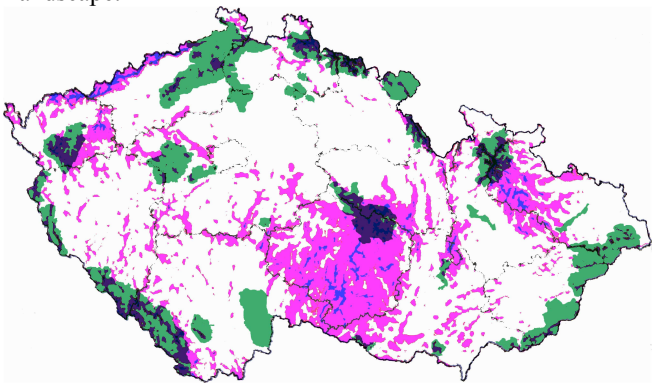

Fig. 2 Elimination of CHKOs and NPs from the Map of Areas Suitable for Wind Power Development

Military areas, important airports and reserved airspace with the lower limit at 300 feet (i.e. 91,5 m) or less above the ground, i.e. a part of so-called

Fig. 3 shows those areas in the map of wind energy potential: military areas (in red), military air lanes (in green) and important airports and reserved airspace specified above (in blue). It is based on the map of lower airspace published on the website of the Light Aircraft Association of the Czech Republic *[Letecká amatérská asociace České republiky]*.

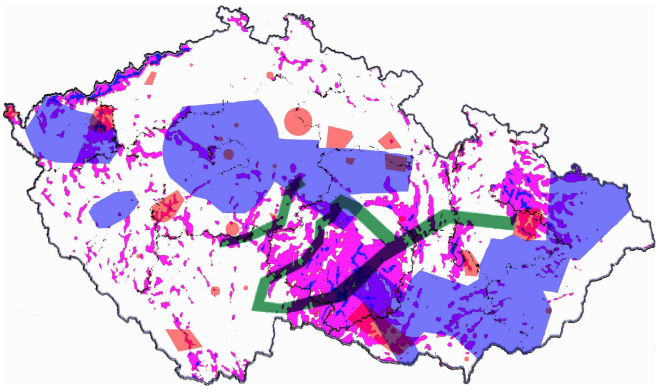

Fig. 3 Military Areas and Reserved Airspace on the Map of Wind Energy Potential

Roads, motorways, railways, important population centres including protective zones of about 500 metres on each side. Important technical infrastructures: oil and gas pipelines, high voltage lines (400 kV, 220 kV and 110 kV) including protective zones of 150 metres on each side

Fig. 4 shows important roads, railways and technical infrastructures on the territory of the Czech Republic eliminated from the map of wind energy potential. The process is based on the maps obtained from the database of the EGÚ Brno Company. The thickness of the lines representing these objects was modified in order to include the object protective zone corresponding to a minimum safe distance from WPPs in case of a WPP accident.

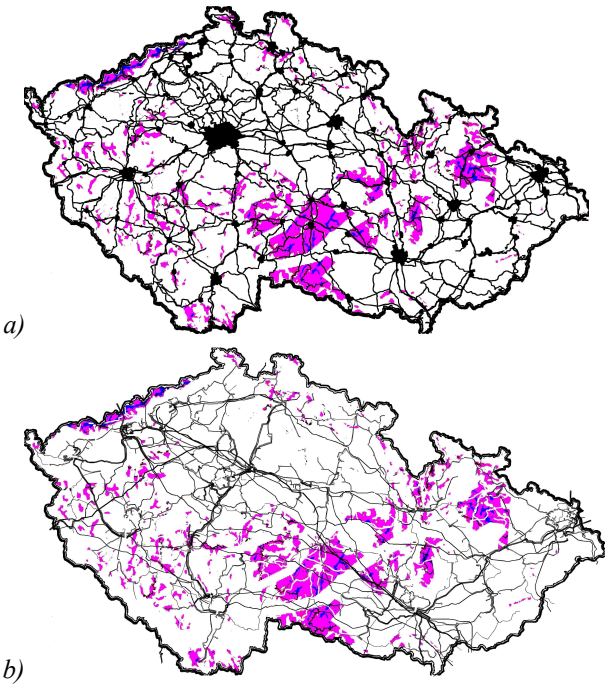

Fig. 4 Limitations of Available Wind Energy Potential Due to a) Roads, Railways and Important Population Centres, b) Important Technical Infrastructures

Principal watercourses and bodies of water in the Czech Republic including protective zones of about 150 metres on each side Figure Insertion, Numbering and References

The area of principal watercourses and bodies of water in the Czech Republic was eliminated from the map of wind energy potential in a similar way – Fig. 5.

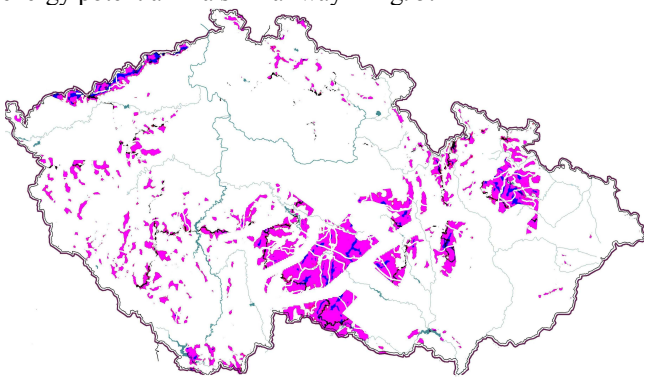

Fig. 5 Principal Bodies of Water in the Czech Republic on the Map of Available Wind Energy Potential

Historical and natural monuments including circular protective zones of 10 km radius according to the principles of landscape protection.

In the last step, natural monuments were taken into account by respecting their protective zones (see Fig. 6). The problems of the influence of construction activities on landscape are treated in Article 12 of the Law No. 114/1992 Coll., which defines landscape character as a natural, cultural and historical feature of a locality. Landscape character is protected from activities diminishing its aesthetic or natural value. Buildings and constructions are authorised only if landscape harmonic proportions are unaffected. This must be

appropriately respected in the methodology of determining wind energy potential. It is most probable that the authorisation of WPP projects in the vicinity of natural monuments will be complicated. That is why these areas are considered unsuitable for wind energy development. Since it is impossible to quantify such subjective concept as "landscape harmonic proportions", it is difficult to define a general rule for an acceptable distance of WPPs from natural monuments.

In this study, each natural monument is surrounded by a circular protective zone of 10 km radius. Taking into account the fact that most of suitable areas are in hilly regions, a protective zone of this size should be sufficient.

Fig. 7 shows the final map representing the areas suitable for wind energy development. They amount to a total area of about 5700 km^2 and the individual limitations respected in the original wind map are listed in Table 1.

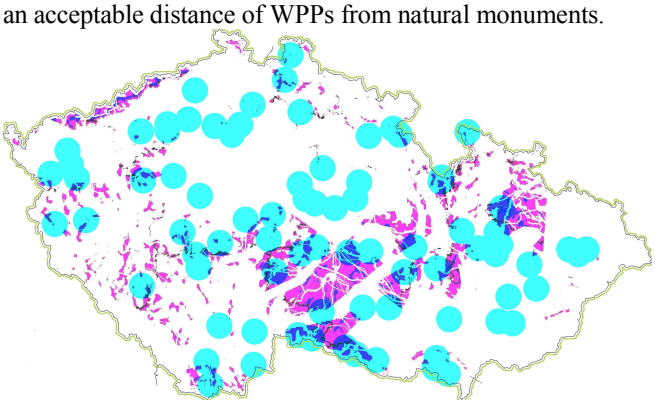

Fig. 6 Elimination of about 70 Historical and Natural Monuments Including Circular Protective Zones of 10 km Radius

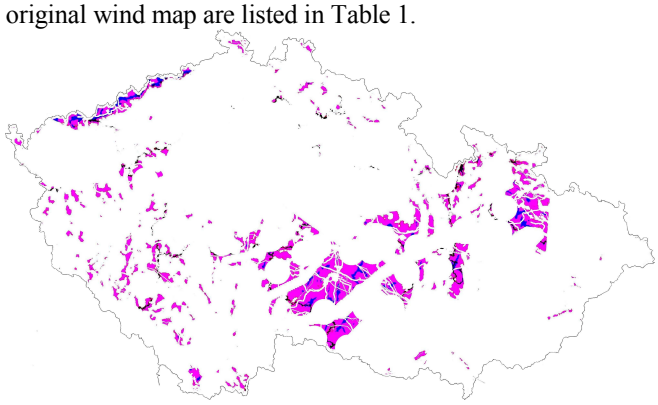

Fig. 7 Final Map of Areas Suitable for Wind Energy Development

Table 1: Area Suitable for Wind Power Development

Known Limitations to Building WPPs	Number of Pixels	Area [km^2]	Change [%]	Share in the Area of the Czech Republic (78864 km^2) [%]
Total area with average wind speeds above 6 m/s	1415608	20400		26
– elimination of protected landscape areas and national parks	1151195	16600	-19	21
– elimination of reserved airspace	662564	9500	-35	12
– elimination of important population centres, roads, motorways, railways	573703	8300	-6	11
– elimination of high voltage lines (400 kV, 220 kV and 110 kV), oil and gas pipelines,	526091	7600	-3	10
– elimination of principal watercourses and bodies of water	510350	7300	-1	9
– elimination of historical and natural monuments	393338	5700	-8	7
The total area suitable for wind power development is 5700 km^2, i.e. about 7 % of the area of the Czech Republic				

The determination of the areas is based on the binarised maps of individual territories where they represent the total number of black-colour pixels.

3 Determination of the Unit Area and Evaluation of the Total Wind Energy Potential

To find the unit area, the following approaches were applied:

1. Analysis of the unit area in existing wind parks, using their area and installed capacity. According to the results in Table 2, the average area necessary for 1 MW of installed capacity is 0,2 km^2.
2. Search in foreign sources dealing with WPP projects. The majority of foreign publications ([3], [4], [5], [6]) put the unit area for WPPs within the range from 0,12 to 0,28 km^2/MW. Those values form a base into which the local geographical conditions of the Czech republic were incorporated:

- most of suitable areas are in highlands and hilly regions (over 500 metres above sea level) in rugged landscape,
- woods were not eliminated from the final area of available potential – 1/3 of the territory of the Czech Republic is wooded,

- density of population in the Czech Republic of 131 people per km^2 – only the urban areas of municipalities exceeding 50 000 inhabitants are represented in the map.

Table 2: Power Densities – Unit Areas of Existing Wind Parks

Wind Power Plant	Yearly Production [GWh/year]	Installed Capacity [MW]	Number of Units	Unit Output [MW]	Average Altitude [m]	Area [km^2]	Power Density [MW/km^2]	Unit Area [km^2/MW]
Germany								
Freiheit III	34,70	16,9	12	1,41	110	3,44	4,9	0,2
Bütow/Zepkow	35,20	19,2	32	0,6	75	4,8	4	0,25
Nechlin	55,90	25,1	15	1,67	35	2,22	11,33	0,09
Uckermark	109	49,1	48	1,02	50	7,35	6,7	0,15
Neuenfeld	59,8	21,5	15	1,43	75	4,38	4,9	0,2
Sonnenberg	130	66	33	2	200	13,44	4,9	0,2
Spitzer Berg	27,4	15,6	12	1,3	75	1,92	8,1	0,12
Quenstedt	22,4	12	8	1,5	220	3,02	4	0,25
Bassens		21	35	0,6	10	2,99	7	0,14
Apensen		34,65	21	1,65	40	3,83	9	0,11
Huje/Nutteln		24,75	15	1,65	25	2,38	10,4	0,1
Weenermoor	40,80	19,5	13	1,5	10	1,91	10,2	0,1
France								
Merdelou/Fontanelle	45,2	15,6	12	1,3	1000	3,26	4,8	0,21
Austria								
Steinberg-Zistersdorf	69,25	30	15	2	300	4,72	6,4	0,16
Auerstahl	47,24	20	10	2	100	3,26	6,1	0,16
Scharndorf	51,70	22	11	2	220	5,49	4	0,25
Petronell-Carnuntum	44,00	24	12	2	170	3,1	7,7	0,13
Neudorf	107,00	44	22	2	200	5,64	7,8	0,13
Zurndorf I+II+III	13,33	6,8	13	0,52	160	4,94	1,4	0,73
Gols	60,00	24	12	2	180	5,92	4,1	0,25
Czech Republic								
Kryštofovy Hamry		42	21	2	850	11,29	3,7	0,27
Average							**5**	**0,2**

The unit area is then determined for two variants:

Variant 1

A minimum of those conditions is respected and a unit area of 0,28 km^2/MW (the upper limit of the range) is used. This corresponds to a WPP power density of 3,6 MW/km^2.

Variant 2

Geographical conditions are taken into account in form of weighting coefficients

$$S_{\mathrm{WPP}} = 0{,}2\ \mathrm{km}^2/\mathrm{MW} \cdot (1 + k_{\mathrm{l}} + k_{\mathrm{w}} + k_{\mathrm{u}}), \qquad (1)$$

where k_{l} represents landscape ruggedness,

k_{w} represents the share of wooded areas in the Czech Republic,

k_{u} represents the share of urban areas in the Czech Republic.

The values of the weighting coefficients were estimated as follows: $k_{\mathrm{l}} = 0{,}45$, $k_{\mathrm{w}} = 0{,}33$, $k_{\mathrm{u}} = 0{,}5$.

Substituting the weighting coefficients yields the value of the unit area:

$$S_{\mathrm{WPP}} = 0{,}2 \cdot (1 + 0{,}45 + 0{,}33 + 0{,}5) = 0{,}456\ \mathrm{km}^2/\mathrm{MW}$$

It corresponds to a density of WPP installed capacity of 2,19 MW/km^2.

Table 3: Analysis Results for Both Variants [1]

Variant	Area suitable for wind power development	Power Density	Available Wind Power Potential	Number of WPPs for Average Installed Capacity of 2,5 MW per Tower	Expected Yearly Production with a Capacity Factor of 2500/8760
1	**5700 km^2**	**3,6 MW/km^2**	**20520 MW**	**8200**	**5,8 TWh**
2		**2,2 MW/km^2**	**12500 MW**	**5000**	**3,6 TWh**

4 ASSESSMENT OF WIND ENERGY POTENTIAL IN INDIVIDUAL NODAL AREAS OF THE POWER SYSTEM OF THE CZECH REPUBLIC

In the final part of the analysis, the wind energy potential is associated with individual nodal areas of the 110 kV transmission system where the power generated by WPPs would have to be supplied to the power system.

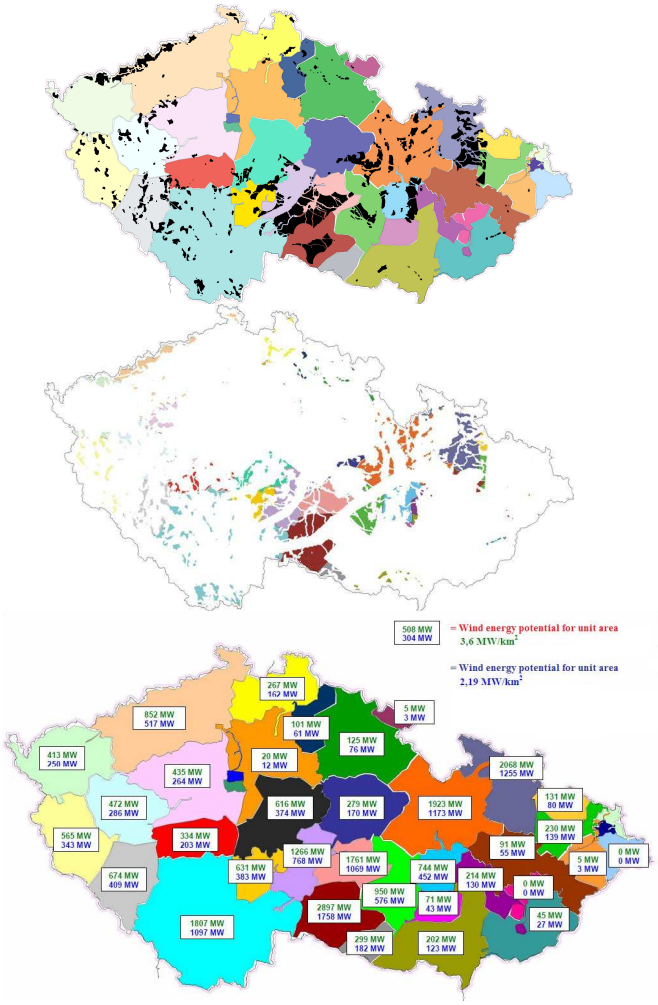

Fig. 8 Assessment of Available Wind Energy Potential in Individual Nodal Areas

To do so, the final map of areas suitable for wind energy development from Fig. 7 is combined with a map of individual nodal areas of the 110 kV transmission system. The total possible installed capacity in a given nodal area is represented by the size of the area which colour corresponds to the nodal area colour. The areas are then transformed into power. The process is shown in Fig. 8.

The constantly increasing interest of investors in renewable energy sources that are generally connected to distribution networks has led to reaching and exceeding the network capacity limits. Today, there are already parts of 110 kV networks in the power system of the Czech Republic where requests for connecting renewable energy sources (mainly wind and photovoltaic power plants) exceed the network capacity and the distribution system operators are obliged to refuse them. Table 4 presents an overview of the available 110 kV network capacity in the Czech Republic in comparison with current investor requests (investor requests – situation as of March 31, 2009; network capacity – situation as of June 30, 2009).

The total available network capacity is not distributed uniformly in the power system of the Czech Republic and does not correspond to the distribution of requests in individual areas. Fig. 9 presents 110 kV nodal areas with available network capacity for connecting new sources in comparison with the areas suitable for wind energy development.

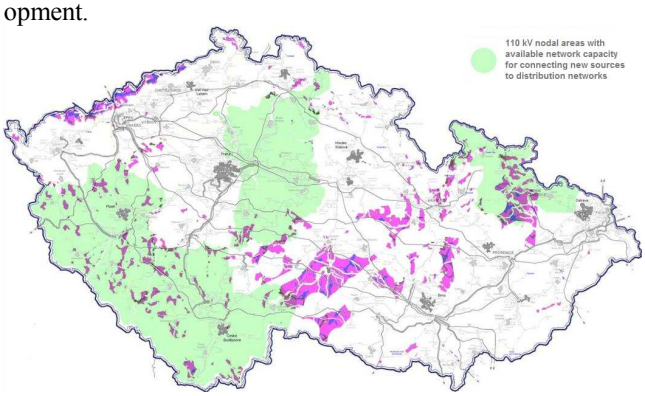

Fig. 9 Current Available Transmission and Distribution Network Capacity in the Czech Republic

Table 4: Comparison of Total Potential, Request and Available Network Capacity [1]

Wind Energy Potential in the Czech Republic	Investors		Network Limitations in the Distribution System	
	Requests for Connecting New Sources	Requests for Connecting New WPPs	Total Available Network Capacity	Available Network Capacity for WPPs
20500 MW / 12500 MW	**8864 MW**	**3234 MW**	**4420 MW**	**1780 MW**

5 CONCLUSIONS

The assessment of the total wind energy potential on the territory of the Czech Republic suitable for wind energy development was established for two variants based on the determination of the area where WPP installation is possible:

Variant 1: 20,5 GW, a rather optimistic value where a higher WPP power density is applied to the total area suitable for wind energy development. It does not take into

account landscape ruggedness or wooded and urban areas. Only the known limitations in form of areas eliminated from the map of wind energy potential on the territory of the Czech Republic were respected.

Variant 2: 12,5 GW, a value closer to the real conditions. However, let us reiterate that only the real conditions that can be quantified by weighting coefficients were respected in the study.

There are further limitations – having a potential considerable influence on the results in both variants – that cannot be respected in the study:

- attitude of land owners to WPP projects,
- attitude of municipalities to WPP projects,
- attitude of regional authorities to WPP projects,
- limitations due to environmental impact assessment,
- network capacity and possibilities of the WPP integration into the power system,
- other limitations (public opinion etc.).

The total potential thus represents the installed capacity of WPPs built in all suitable areas in the Czech Republic (respecting the above-mentioned limitations). Taking into account wind energy potential and estimated WPP density, a typical landscape in, say, the Bohemian-Moravian Highlands could look like this:

ACKNOWLEDGEMENTS

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