

VALORIZATION OF POTENTIALS OF WIND ENERGY IN MONTENEGRO

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Investments in energy sector are usually long term processes both in construction and exploitation phase, and therefore requires many conditions to be satisfied, mostly from legislative and technical sector. While the legislative can change in accordance with economy activities in the country, technical data (on-site measurements) which are the main base for energy facility design, need to be reliable as much as possible. Wind energy has a significant global potential which exceeds the world's electrical energy consumptions. This paper presents the estimation of wind energy potentials in Montenegro, based on all previous available studies in this field. The wind energy potential in Montenegro is based on a combination of a three-dimensional numerical simulations of wind fields on the entire territory, and comprehensive on-site measurements. The preliminary studies shows that there is a potential of areas with high and mean values of a capacity factor about 400 MW, and annual production of 900 GWh of electric energy. The share of wind parks in the total installed power in Montenegro is planned to be about 8%, while an adequate ratio of wind parks in an annual production from renewable sources (large hydro power plants are included here) is estimated to be 11.4%. The paper presents the current state of art in the field of building of wind parks in Montenegro. A particular attention was paid to the legislation framework and strategic documents in the energy area in Montenegro.

Key words: *wind, wind energy, estimation of potential, wind generator, wind park*

1. Introduction

Within the global economy, dominated by a trend of fast changes, the ability of self-satisfying of energy needs has a significant role in the planning of future in each country. For the purpose of reduction of reliance on fossil fuels and foreign sources of energy, many countries have initiated programs of researches and development in the field of renewable energy sources (RES). Wind energy is one of the renewable sources which global potential exceeds several times the need for electrical energy [1], [2].

As one of candidate countries for EU accession, Montenegro is obliged to meet certain EU standards, i.e. to adjust its regulations and legal system, in all sectors, including energy.

This paper describes all the activities that are realized in Montenegro with the goal of valorization of wind energy potential through the harmonization of national with EU legislation. The paper also presents all the analyzes (based on theoretical studies, numerical simulations and

measurements) carried out to assess the wind energy potential in Montenegro. The paper also presents basic information for the two projects: wind park Krnovo (72 MW) which is completed and Možura (46 MW) which is in its initial stage of construction.

2. Energy policy of the EU and Montenegro

2.1. The current state and developmental trends in the EU

In order to protect the environment and to reduce greenhouse gases effects, permanent efforts related to increasing of use of electrical energy from renewable sources are made. In 2001, the EU member states adopted the guidelines for the increasing of the number of renewable energy sources in the total consumption from 6% to 12% in 2010. The European Parliament in 2005 approved the recommendation for further increasing of share of renewable sources in the total consumption to 20% in 2020, with saving of energy of 20% and the reduction of production from fossil fuels to the level of 20%.

The wind energy has a dominant part between all renewable energy sources in the EU countries. The increasing of total installed power of wind power plants in the EU countries and the rest of the world for the period from 2000 to 2015 is presented in Fig. 1. At the end of 1995 there were 4.800 MW capacities installed, and 59.000 MW installed at the end of 2005 (increasing of 12 times for 10 years). In the period between 2000-2007, the biggest increasing of installed capacities is related to gas power plants (76.6 GW), followed by wind parks (46.8 GW), while the increase of installed capacity of thermo-electrical power plants, heavy-oil power plants and nuclear power plants is rather smaller. (32.2 GW in total). In accordance with the EU recommendations in 1997, the plan was to have 40 GW of wind parks until 2010, and this goal had already been achieved in 2005, Fig. 1. The EWEA (European Wind Energy Association) increase this goal to 80 GW. Such a trend can be compared only with the increase of the computing or nuclear industry in 1960s and 1970s.

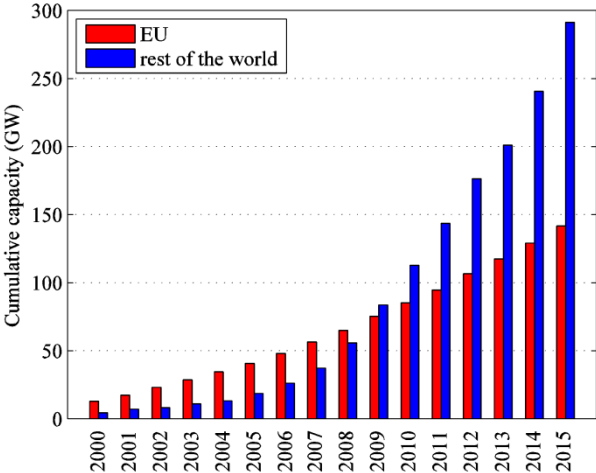


Figure 1. Cumulative wind power capacity 2000 – 2015 [3, 4]

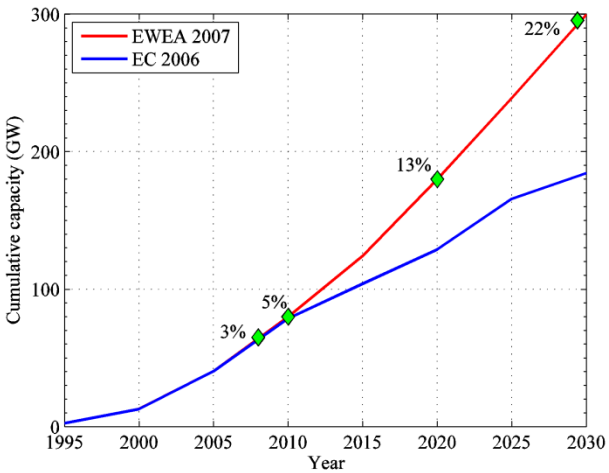


Figure 2. Projection of growth of installed power of wind generators in the EU and a corresponding effect on the reduction of CO₂emission [5]

Whereas the use of wind energy is followed by big investments, the increase of production of electrical energy from wind energy is an exponential one. The forecasts up to 2030 say that this trend

will be continued (according to the projections by EWEA of 2007) or mildly slowed down (according to projections by The European Commission of 2006), Fig. 2. The same figure gives the estimation of the impact of the new wind parks on the CO₂ reduction in percent, at some particular time points. It can be seen that the reduction of CO₂ emissions, which are the main reason of the global warming, can be expected only in the next period, when the wind park capacities become more significant and its use become constant.

Although the industry of wind energy equipment has been most dynamic in Europe and North America so far, new markets are being opened in Asia (India and China) and South America (Brazil). Fig. 3 gives the data about the installed power of wind generators in the world in 2015 [4].

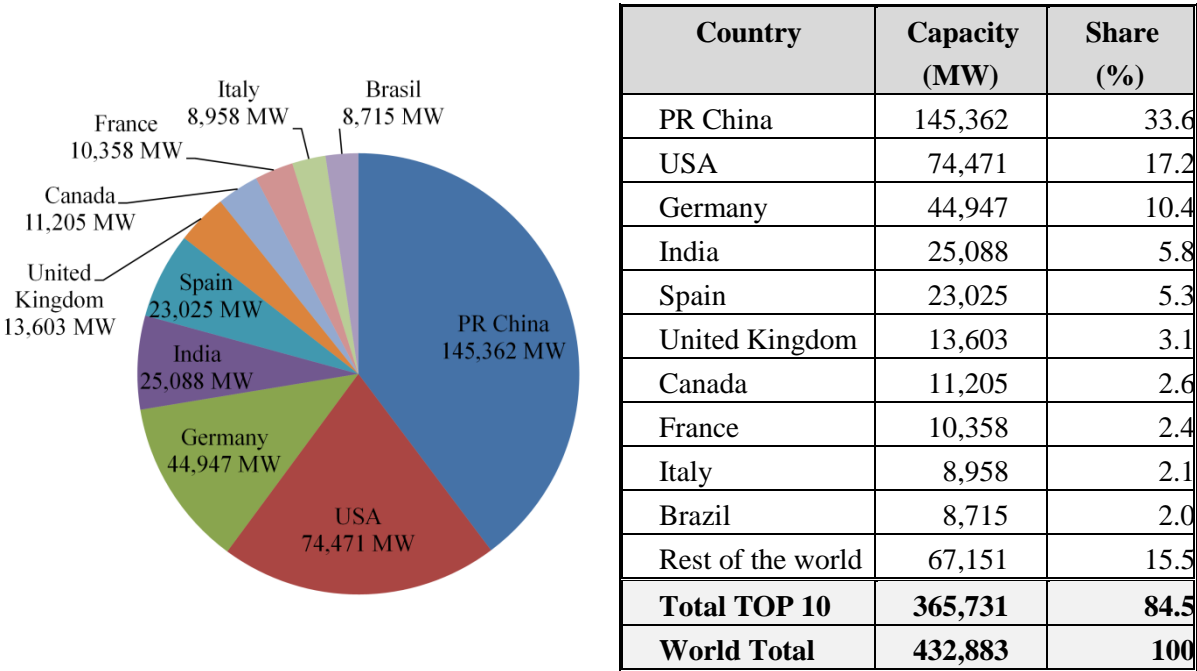


Figure 3. Cumulative installed capacity in December 2015 [4]

Mainland locations for the mounting of wind generators in some countries are almost entirely used and wind parks are being installed offshore. Germany and Denmark achieved a particularly big advancement in this filed.

2.2. Wind energy in the strategy of energy development in Montenegro by 2030

In March 2011, The Government of Montenegro adopted an updated and amended Energy policy of Montenegro [6]. This document is a basis both for the preparation of the strategic energy development in Montenegro by 2030 [7] and for the action plan for its realization [8]. New energy policy defines the aims of energy development of Montenegro by 2030 as well as the main priorities and key strategic trends. The main priorities are: reliability of power supply, development of competitive energy market and a sustainable energy development. Based on the priority directions in The European Union, the state's goals in the energy area are the growth of the reliability in the power supply, growth of use of energy from renewable sources, improvement of the energy efficiency, investment attraction and the development of market competition in the area of energy. Based on the presented results of the analysis of potentials of wind energy, the development of wind parks was planned by the strategy of development in Montenegro by 2030. According to the reference scenario,

the first wind park should have been put into operation (in 2014), and the additional capacities of wind parks should have been put into operation in already in 2015. The overview of the planned development of the wind parks by 2030 is given in Table 1.

Table 1. Overview of the planned development of wind parks by [7]

Planned wind parks	Start of the realization of the project	Installed power (MW)	Annual production (GWh)
Wind park Možura (Bar/Ulcinj)	2014	46	105.8
Wind park Krnovo (Nikšić)	2015	50	115
Wind park Krnovo (Šavnik)	2015	22	50.6
Wind parks (undefined location)	2016	7.5	17.2
Wind parks (undefined location)	2020	25.7	59.2
Wind parks (undefined location)	2025	17.1	39.3
Wind parks (undefined location)	2030	21.4	49.2
Total	2030	189.7	436.3

The development of the total installed power of the energy system (EES) of Montenegro by 2030 is presented in Fig. 4.

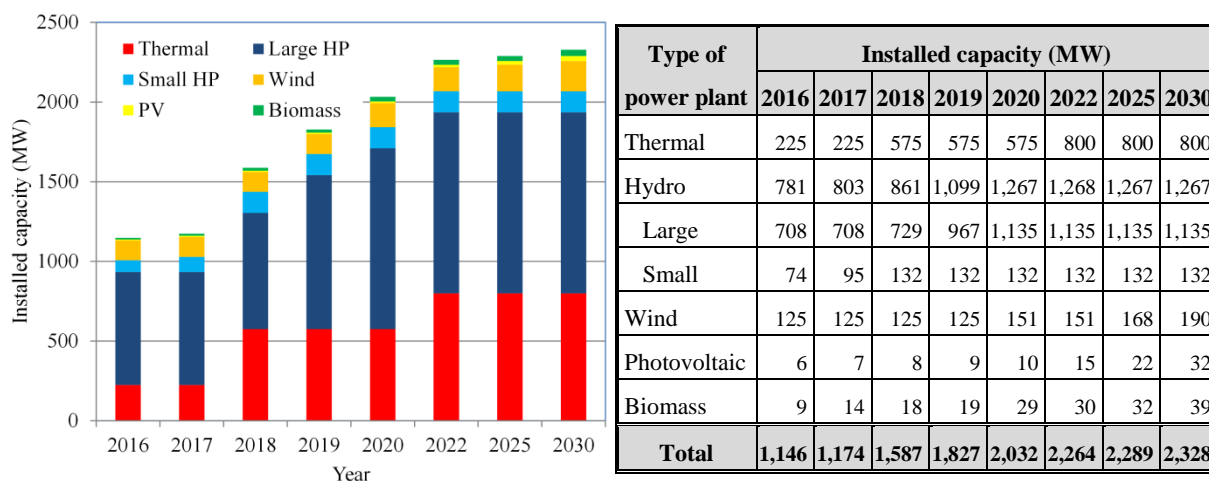


Figure 4. Development of installed power in EES in Montenegro by 2030 [7]

Projections of using of renewable energy sources for electrical energy production according to the aims of Directive 2009/28/EC is presented in Fig. 5.

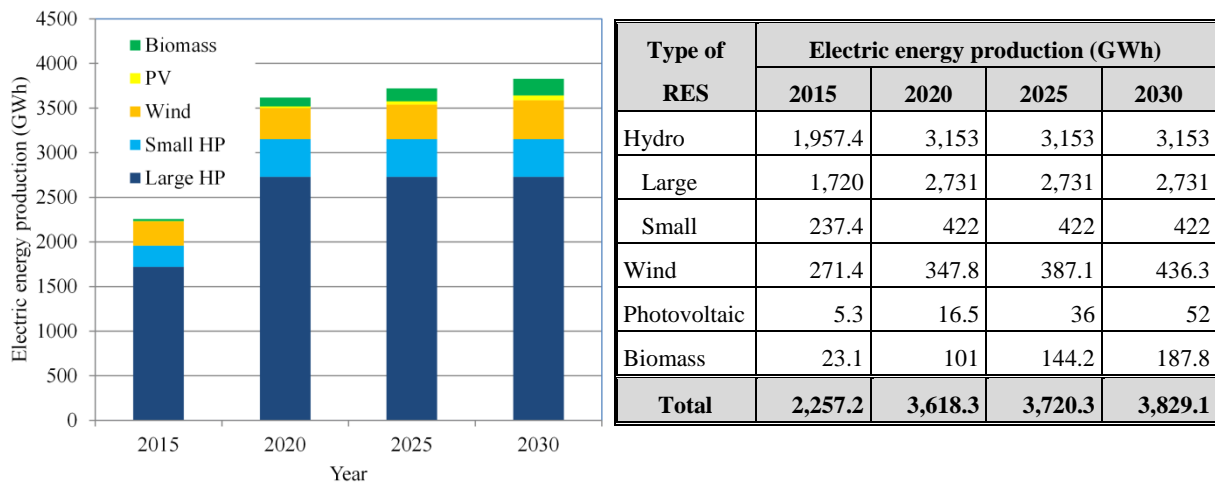


Figure 5. Electrical energy production from renewable sources by 2030 [8]

In accordance with data presented in Fig. 4-5, the ratio of wind parks in the total installed power in this period will increase from 8% up to the 11%. In this scenario, the wind parks will take third place regarding the installed power, after large hydro and thermal power plants. The long time projection for wind parks until 2030 is about 190 MW of installed power, with an annual electricity production of 440 GWh.

3. Potential of wind energy in Montenegro

A proper evaluation of renewable energy potential has a main importance for sustainable energy policy of any country, where the wind energy is one of observed factors. Evaluation studies of wind energy potentials for the countries of the former Yugoslavia can be found in: Poje and Cividini [9] for Croatia, Zlomušica [10] for Bosnia and Herzegovina, Dimcev et al. [11] for Macedonia. The first theoretical analysis of wind potentials for the territory of Serbia and Montenegro was given by Mikičić et al. [12]. In this analysis, the estimation of the wind energy potential was obtained based on anemographic on-site measurements in meteorological stations. These data were used for the estimation of a degree of similarity of winds in Serbia and Montenegro, to the winds in Denmark and Germany, and on the basis of which the estimation of winds in Serbia and Montenegro was executed in a comparative analysis. Knowing that the technically usable potential of winds that at the height of 10 m above the surface have an average annual mean speed higher than 5.1 m/s, only these values of wind speeds were used in the comparative analysis.

The first detailed study in which the wind potential in Montenegro was analyzed [13] was based on the results of the simulations obtained by the use of a three-dimensional macroscopic numeric model that are afterwards calibrated with the results obtained on the spot. The estimation of energy potential of wind for the entire territory of Montenegro was performed first. The results of this analysis are presented as wind maps presenting the theoretical mean wind speed (Fig. 6) and theoretic mean wind potentials (Fig. 7) on reference height of 50 meters above the ground.

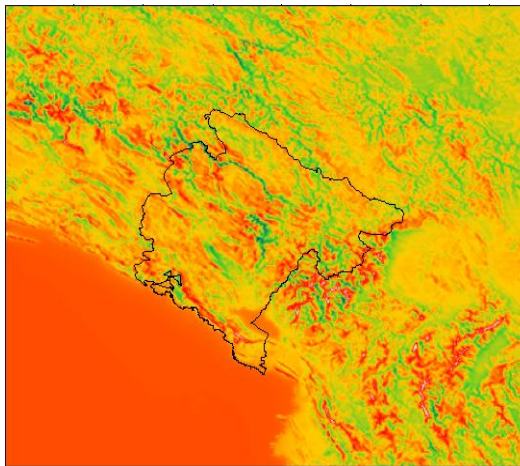


Figure 6. Theoretic mean wind speed [13]

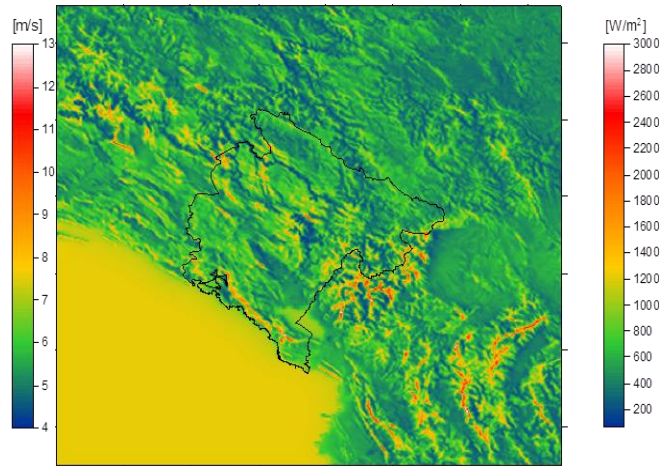


Figure 7. Theoretic mean energy wind potential [13]

After this, the correction of the results was performed in order to obtain a real mean wind speed and real mean energy wind potential. The correction by using an adequate factor obtained by comparison of the simulated and measured wind speed, was firstly executed. Then, after the detailed analysis, the corrections taking into account all relative limits influencing the reduction of usability of energy wind potential were executed. These limits include the terrain topography, accessibility of the location, distance from the road network and connection to the electrical grid, closeness of settlements and natural parks etc. The final results of these corrections are the maps presenting the real mean wind speed (Fig. 8), and a real mean energy wind potential (Fig. 9) on the height of 50 meters.

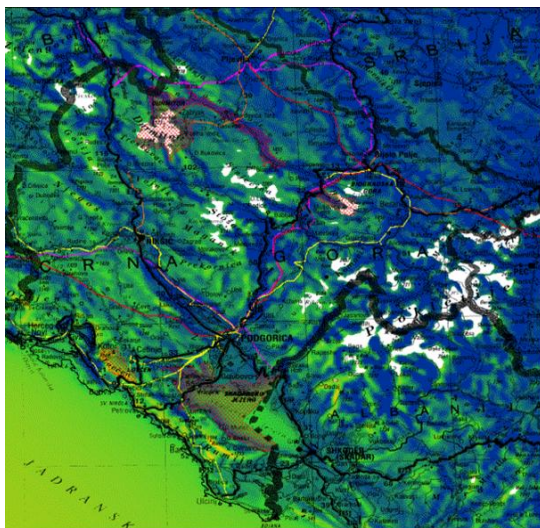


Figure 8. Real mean wind speed [13]

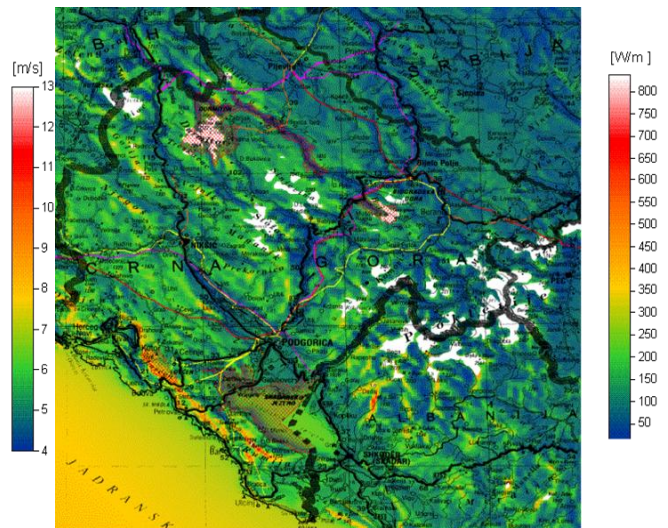


Figure 9. Real mean energy wind potential [13]

These analyses showed that the wind speeds at the largest part of Montenegro are below 5 m/s. The building of wind parks mainly is not economically viable in cases of these wind speeds. Although, it has been shown that some areas have a significant potential for utilization of wind energy and these places, at the same time, are situated in the vicinity of traffic and electrical networks. First of all, it

purports to the coastal area where wind speeds have a range from 5 to 7 m/s, and at some locations along the coastal areas these wind speeds have values 7 to 8 m/s (mountain massif Rumija, hinterlands of Petrovac, mountains in hinterlands of Herceg Novi and Orahovac). Except the seaside, an important wind potential is found in the region of Nikšić, where the mean values of wind speeds range from 5.5 to 6.5 m/s. The analysis has shown that other locations characterized by big wind speeds are not attractive for the time being for the building of wind parks because these are positioned on high mountain regions, at mountain slopes, or these are far from the existing road and power supply infrastructure. The problem of the connection of wind parks in Montenegro to the adequate electric grid is particularly pronounced. For the biggest part of Montenegro, the typical real mean energy wind potential is within the limits of 100 to 300W/m², while in the mentioned areas in the seaside and around Nikšić it exceeds the level of 400 W/m².

The study [13] analyzed several scenarios of use of wind potential in Montenegro. The most windy areas that are most convenient for the building of wind parks (wind speeds bigger than 7 m/s, namely the capacity factor bigger than 30%, Fig. 10), have a capacity of about 100 MW. The areas with mean values of windspeeds and a capacity factor (wind speed from 6.4 to 7 m/s and capacity factors from 25 to 30%) have an additional capacity of 300 MW. By exploitation of the mentioned potential of 400 MW in total, the annual production of electrical energy of 900 GWh would be accomplished, what approximately correspond to one fourth of consumption of electrical energy in Montenegro. Note that all the mentioned analyses were conducted for the height of 50 meters and the use of higher towers, namely wind generators with higher installed power would enable use of bigger wind speeds, and a bigger capacity factor could be obtained.

Since 2007, besides the mainland area of Montenegro, Italian, Croatian and Albanian partners, in cooperation with the ministries responsible for energy, have been working on the project of the estimation of wind potentials at The Adriatic Sea within IPA Adriatic Programme of a cross-border cooperation [14]. This project is focused on the estimation of offshore wind potential through the elaboration of a numerical model, as well as the placing of measuring devices on coasts for the purposes of calibration of obtained results. The mean wind speeds for 2012 at the part of the Adriatic Sea by the Montenegrin coast are presented in Fig. 11.

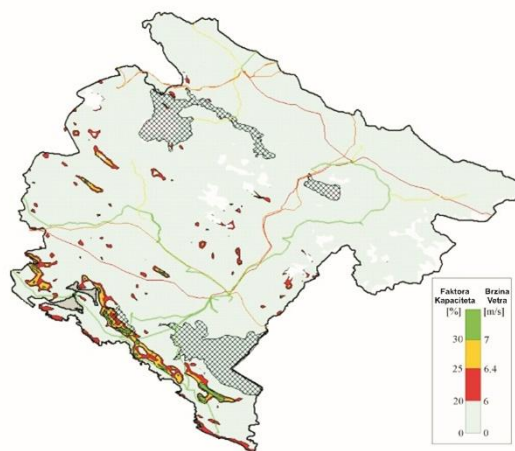


Figure 10. Wind speed – intervals of capacity factor [13]

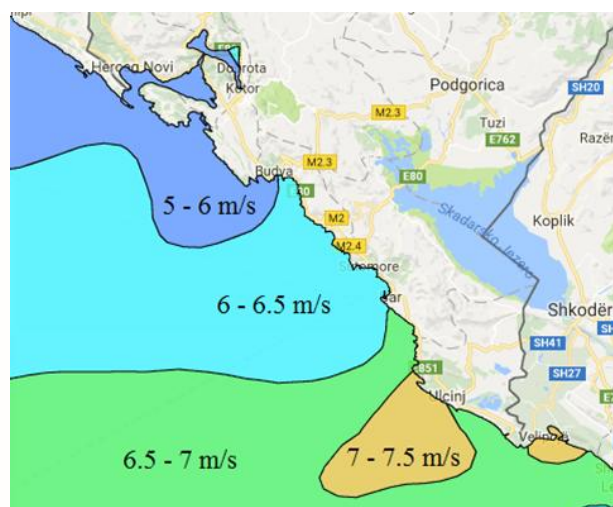


Figure 11. Real mean wind speed at the part of Adriatic sea by The Montenegrin coast [14]

Similar project was also performed within the 6th Framework Programme of the European Commission which was finished in 2015 [15]. One of the results of this project is the wind maps for the territory of republics of former Yugoslavia.

The Danish manufacturer of wind generators made the map of winds in Montenegro which gives the wind speeds at the height of 80 meters [16].

Note that the Institute of Hydrometeorology and Seismology of Montenegro has also been performing a systematic on-site measurements of hydrometeorology parameters for its own needs, as well as the wind parameters for more than 20 years. The data are measured in the points that are situated in urban environments (mostly in towns), and that are mostly in lower areas and valleys. Many data that are obtained and analyzed in this way are mostly intended for the purposes of various analyses and studies that are conducted in The Institute of Hydrometeorology and Seismology of Montenegro.

Wind speed in the lower layers of the atmosphere is affected by terrain configuration, vegetation and buildings. As it can be noted, different studies use different reference height above ground, e.g. 50 m, 80 m, etc. It is possible to compare those data on different heights, considering that the roughness effects in the atmospheric boundary layer can be described using logarithmic profile:

$$\frac{V_m(z)}{V_m(z_{ref})} = \frac{\ln z - \ln z_0}{\ln z_{ref} - \ln z_0} = \left(\frac{z}{z_{ref}} \right)^\alpha \quad (1)$$

where z represents the height above the ground, z_{ref} is the reference height, z_0 is the roughness height and α is the terrain roughness coefficient. Typical values of z_0 and α can be found in [17].

4. The current state in the building of wind parks in Montenegro

Relying on data from study [13], four companies obtained the permission from the responsible ministry for on-site measurements and research of wind potentials at the Montenegrin territory. The reports of analysis of collected data of wind potentials have been submitted for two locations so far: Krnovo and Možura [18], [19]. Based on the results of measurements in December 2009, a public bid for these two locations was announced and the contracts about the land rent and building of wind parks for these two locations, Krnovo and Možura, were signed latter.

The area around the wind park Možura is situated northerly from Ulcinj, at the coastal part of the mountain Možura, far a little more than 5 km of airline from Ulcinj, at about 17 km far southerly from the nearest point of the Skadar lake, and at about 17 km north-westerly from Ada Bojana. The mountain Možura stretches along the southeast – northwest direction in length of about 8.5 km, and the height where the installation of wind generators is planned ranges to 622 meters above sea level. This location territorially belongs to the municipalities of bar and Ulcinj. The projected installed power the wind park Možura is 46 MW with the estimated annual production of about 100 GWh. The value of the project was estimated to be about 80 million EUR. The contract about land rent for the period of 20 years and the building of the wind park at the location of Možura was signed in July 2010 with the consortium Fersa Energias Renovables from Spain and Čelebic from Podgorica [18]. After the providing of all necessary documents, the Ministry of sustainable development and tourism issued the building permission for the building of the wind park in December 2014, however, the investors were interested to transfer their rights and obligations to the Enemalta plc from Malta, what was latter

realized. The estimated reduction of CO₂ emission due to the building of this wind park is about 80,762 t/year.

The area around the wind park Krnovo is at the territories of Šavnik and Nikšić, at sea level above the 1500 meters. The projected installed power of the wind park Krnovo is 72 MW, and the estimated annual production is about 160 GWh. The value of the project was estimated to be about 120 million EUR. The investor is the consortium of companies Ivicom Consulting from Austria and Akuo Energy from France. The estimated reduction of CO₂ emission due to the building of this wind park is 212,960 t/year.

For the first 12 years of operation, the contracts provide the guaranteed purchase price for the energy produced in wind generators is 95,99 €/MWh. The purchase price is prescribed by the regulation for the stimulation of price of energy from renewable sources [20]. Table 2. gives the mean wind speeds measured at the locations of Možura and Krnovo, while Table 3 gives basic technical data for both projects.

Table 2. Mean wind speeds (m/s) and measured at the locations of Možura and Krnovo [18], [19]

Location	Month												Average
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Možura	6.6	7.5	7.3	6.0	5.2	5.1	5.0	5.4	5.3	6.1	7.1	7.6	6.2
Krnovo	6.7	9.1	8.7	5.0	5.6	5.2	5.3	6.1	7.0	5.3	5.6	8.1	6.5

Table 3. Basic technical data for wind parks Možura and Krnovo

	Wind park Možura	Wind park Krnovo
Number of wind generators	23	26
Installed power	46 MW	72 MW
Rotor diameter, number of blades	do 121 m, three blades	do 103 m, three blades
Tower height	Up to 90 m	Up to 100 m
Year of manufacturing	115 GWh	220 GWh

The installation of wind generators at the location of Krnovo was done in September and October 2016, and the trial operation and of exploitation permission are planned to May 2017. For the location of Možura, the preparations for the final works are planned for the beginning of 2017.

5. Conclusion

Based on the previous research, it can be concluded that Montenegro has a significant potential for building wind parks for electrical energy production. The preliminary studies based on the numerical simulations indicate that there is a potential of areas with high and mean values of a capacity factor about 400 MW, and that exploitation of this potential means an annual production of electrical energy of about 900 GWh, corresponding approximately one fourth of total consumption in Montenegro. However, further comprehensive research is necessary, especially in the field of measurements on the terrain in order to determine potential of energy more precisely. The strategy of energy development of Montenegro by 2030, provides the building of wind parks with total installed power of 190 MW and an annual production of 440 GWh. In this way, the share of wind turbines in

the total installed power of the energy system of Montenegro is planned to be a little more than 8%, while an adequate share of wind parks in an annual production from renewable sources (large hydro power plants are included here) is estimated to be 11.4%. In case that planned scenario became true, the building of wind parks would have a significant role in the realization of goals prescribed by the directive 2009/28/EC, in sense of an increasing of the share of electrical energy produced by utilization of renewable sources, as well as in sense of reduction of emissions of greenhouse gasses.

The project of the building of the wind on the location of Krnovo with installed power of 72 MW has been finished and it represents the first concrete project that exploits potential of wind energy in Montenegro. The project of the building of the wind park on the locality of Možura with installed power of 46 MW is in the phase of preparatory works. With the realization of these two projects, 60% of wind parks planned in the strategy of energy development of Montenegro by 2020 will be achieved.

References

- [1] The Ministry of Finance of Montenegro, Montenegro development directions 2015 – 2018, Podgorica, 2013
- [2] Patel, M., *Wind and Solar Power Systems: Design, Analysis and Operation*, Second Edition, CRC Press, Boca Raton, USA, 2005
- [3] EWEA, Wind in power – 2015 European statistics, Brussels, 2016
- [4] GWEC, Global wind report - Annual market update 2015, Brussels, 2016
- [5] Zevros, A., Kjaer, C., Pure Power: Wind Energy Scenarios up to 2030, Report No. 62, EWEA – European Wind Energy Association, Brussels, 2008
- [6] The Ministry of Economy of Montenegro, Energy policy of Montenegro until 2030, Podgorica, 2011
- [7] The Ministry of Economy of Montenegro, Energy development strategy of Montenegro by 2030, Podgorica, 2014
- [8] The Ministry of Economy of Montenegro, Energy development strategy of Montenegro by 2030 Action plan 2016-2020, Podgorica, 2015
- [9] Poje, D., Cividini, B., Assessment of wind energy potential in Croatia, *Solar Energy*, 41 (1988), 6, pp. 543-554
- [10] Zlomušica, E. H., Wind Energy Resources in Bosnia and Herzegovina, *Thermal Science*, 14 (2010), 1, pp. 255-260
- [11] Dimcev, V., *et al.*, Wind energy potential assessment in Republic of Macedonia, *Journal of Energy and Power Engineering*, 5 (2011), pp. 324-330
- [12] Mikicic, D., *et al.*, Wind Energy potential in the World and in Serbia and Montenegro, *FactaUniversitatis*, 19 (2006), pp. 47-61
- [13] Barbieri, C., Gianluca, C., Assessing the potential of renewable energy sources in the Republic of Montenegro: A summary assessment of the energy potential of wind, sunlight and biomass, Ministry of the Environment and Protection of Land and Sea of Italy, Italy, 2007

- [14] ***, Project of Offshore Wind Energy: Research, Experimentation, Development (POWERED), www.powered-ipa.it
- [15] ***, The South Eastern European Wind Energy Project (SEEWIND), www.seewind.org
- [16] Vestas, Wind resource map of Montenegro, 2010
- [17] Živković, P. M., *et al.*, Hybrid soft computing control strategies for improving the energy capture of a wind farm, *Thermal Science*, 16, (2012), pp. 483-491
- [18] Ivicom Wind d.o.o., Results of the research of the wind potential at the location Krnovo (Gvozd, Bukovik, Horse) in the period from September 2008 to September 2009, Podgorica 2009
- [19] Fersa Energias Renovables, Results of the research of the wind potential at the location Možura (Ulcinj, Ulcinj2) in the period from May 2008 to May 2009, 2009
- [20] Official Gazette of Montenegro 52/11, 28/14 and 79/15, Decree on the tariff system for determining incentive prices for electricity from renewable energy sources and high efficiency cogeneration, 2011