Comparison of roughness index for Kitka and Koznica wind farms

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ABSTRACT

Kosovo has limited renewable energy resources and its power generation sector is based on fossil fuels. Such a situation emphasizes the importance of active research and efficient use of renewable energy potential. According to the analysis of meteorological data for Kosovo, it can be concluded that among the most attractive potential wind power sites are the locations known as Kitka (42° 29' 41" N and 21° 36' 45" E) and Koznica (42° 39′ 32″ N, 21° 22′30″E). The two terrains in which the analysis was carried out are mountain areas, with altitudes of 1142 m (Kitka) and 1230 m (Koznica). the same measuring height, about 84 m above the ground, is obtained for these average wind speeds: Kitka 6,667 m/s and Koznica 6,16 m/s. Since the difference in wind speed is quite large versus a difference in altitude that is not being very large, analyses are made regarding the terrain characteristics including the terrain relief features. In this paper it will be studied how much the roughness of the terrain influences the output energy. Also, that the assumption to be taken the same as to how much they will affect the annual energy produced.

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1. INTRODUCTION

Because of the harmful consequences of pollution from the emissions of various gases, renewable energy sources increasingly gain in importance. The wind is a natural phenomenon related to the movement of air passes caused primarily by differential solar heating of the earth's surface [1], [2]. European countries by an agreement have decided to supply 20 percent of its total energy demand from renewable sources by 2020. We are now one year after that agreement, and we can see how far Kosovo has come in achieving this goal. This goal has been achieved by considering biomass as it is not widely used for heating needs, while other renewable sources remain largely in the shade. The potential is for all resources, but legal regulations have been able to develop to a limited extent. In two years (2008 and 2009), more than 24,000 MW of new power capacity based on wind energy was installed in the EU countries [1]. Nowadays, wind energy, as an alternative clean sustainable energy source, has been recognized as one of the fastest developing renewable energy source technologies. Wind power generation has made a remarkable contribution to daily life across the globe and has grown rapidly over the past 20 years [3]. As a renewable energy source with the highest growth rate in the last two decades, wind energy is considered a very important resource of electricity production in the future. The forecasts for the development of wind energy are highly optimistic and state that this type of energy will be important in the future [4], [5]. Wind turbines operate at altitude, and it is important to know what happens to air density as altitude increases. The density of air varies with altitude, so it is a decreasing function. So above, the air is lighter. This allows less aerodynamics to be created spontaneously [6], [7].

The primary meteorological factor in evaluating a prospective wind turbine site is the mean wind speed. Another important parameter is the anticipated extreme wind speed [8], [9]. Wind power plants generate electricity when the wind is blowing, and the plant output depends on the wind speed. Wind speeds cannot be predicted with high accuracy over daily periods, and the wind often fluctuates from minute to minute and hour to an hour [10], [11]. In fact, the wind also varies every second due to turbulence caused by land features, thermal sources, and specific weather conditions. It also blows more strongly higher above the ground than closer to it, due to surface friction [12], [13].

Total energy production and capacity factor are fundamental aspects of a wind power project. To determine the optimum energy output, it is essential to select the right turbine design for a location [14]. Wind turbine operation is dependent on wind speeds to generate power [15]. Sustainability evaluation of wind resources can be performed using different approaches that are complementary between each other: thermo-economic analysis (energy and/or exergy calculations), life cycle assessment (which is a multicriteria product-oriented analysis), emergy approach (a holistic approach donor side oriented). These different assessment approaches were compared one by one and/or combined [16], [17].

Annual energy produced is typically calculated referring to the annual mean wind speed of the site. Unfortunately, the annual average wind speed varies significantly [18]. Operation of the individual wind turbines may be adversely impacted by the turbulent wakes from other upwind turbines, with the magnitude of the impact depending largely on the turbines' respective rotor sizes and distance between one another, as well as on the overall shape of the wind farm and turbine spacing therein [19]. Wind shear in open ground when dealing with distances e.g., 10m in it have a greater effect than what is found in the field. Now increasing the height these do not have high impact. This effect, however, has the effect of reducing the energy generated by a turbine, and then the entire wind farm [20], [21]. The electricity factor produced by wind energy ranges from 20 to 40%, in general [22], [23]. The value of the capacity factor for wind turbines in Kosovo is estimated to be 25% [24]. Based on the analysis done, we can assess precisely whether these two places have the potential to contribute to the local energy production.

2. RESEARCH METHOD

The methodology used in this paper consists of consulting, studying, analyzing, and comparing the data for wind speed, wind direction and the main components to analyze the roughness in those terrains. In this case there are used one year measurement for two wind farms, Kitka and Koznica. This method of analysis is simple, and we assume or hypothesize that: in our case we are dealing with two mountain terrains, we have the same wind direction, and their geographical coordinates (Koznica: N 42.59880°; E 21.35468°, Kitka N 42.3956° E 21.3936°) are very close so we will expect to have results same to the effect of roughness.

2.1. Site description and data's for Koznica

The WPP Koznica is in Kosovo, approximately 16 km south-east of Pristina and 7 km west of Novo Brdo. For the analysis of wind characteristics and wind energy potential of the Koznica site, the measurement data for the one-year period 01/05/2015 – 30/04/2016 have been used. The turbines presented in Table 1, are not located at the same distances, due to the unsuitable terrain, but the placement was done using WAsP software.

Table 1. Details of all turbines placed in Koznica

Turbine no.	Coordinate of turbine placement X(m)	Y(m)	Level above sea (m)
"T1"	529087	4716298	1009
"T2"	528927	4716930	1009
"T3"	528909	4717540	1027
"T4"	529631	4717188	996
"T5"	529051	4718563	988
"T6"	528709	4718886	998
"T7"	528910	4720283	1084
"T8"	529198	4719972	1052
"T9"	529555	4719986	1081
"T10"	529843	4720214	1071

Koznica is determined with the database ESA Globcover 2009. Modeling of the terrain roughness was conducted by estimating the roughness length of the field in accordance with the methodology of the

European Atlas of the winds. By using this database and the software package WAsP Map Editor, the map of the roughness of terrain was made that included a wider target region comprising 20x20 km^2 of the territory of the target region. Changes in the roughness of the terrain of the target region Koznica, which was used for making the WAsP folder, is shown in the satellite image of the terrain (Google Earth) in the figure below. In this figure, the location of WPP Koznica is indicated with red contour line. The terrain shown in Figure 1 on which the construction of WPP Koznica is planned is relatively simple in terms of roughness and can be described with afforested valleys with relatively high roughness, and bared ridges where the construction of wind turbines is planned. Layout of ten wind turbines in Koznica is well shown in Figure 2, where the sitting of them is focused in that way that tends to save 3D distance.

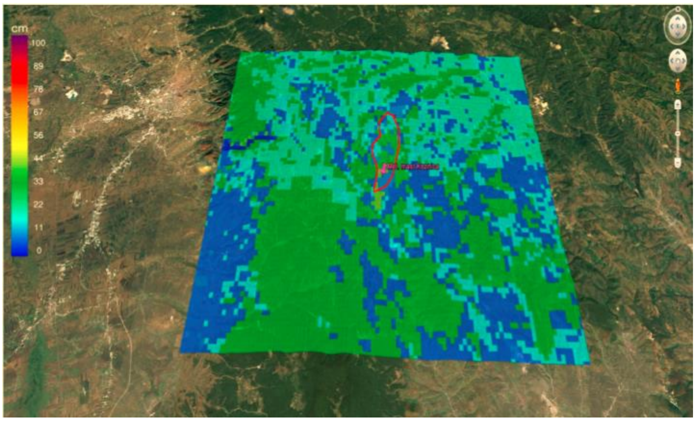

Figure 1. The roughness map of the wider terrain at the target region of WPP Koznica (which is indicated in red contour line)

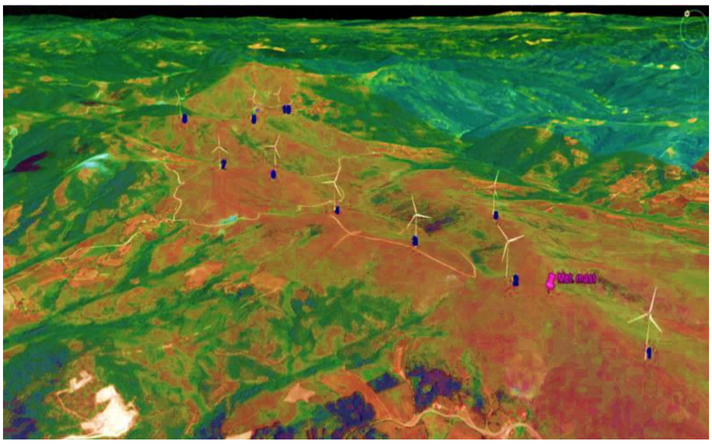

Figure 2. Layout for the 10 turbines for the project WPP Koznica

2.2. Site description and data for Kitka

Kitka wind farm site is in a complex mountainous region, shown in Figure 3. Although the slopes of the terrain were high, no cliffs were observed. Turbines are planned on the plateau of mountain ridge running northwest-southeast direction. Site elevations range from 960 m to 1090 m from sea level. The terrain here is made up of grass of agricultural land and forest areas [25], [26]. Since we are dealing with mountainous terrain, then here too there are trees, but they are far from the place where the wind turbines are placed. Low-density rural settlements are present in the vicinity, and this has been taken into consideration while wind turbine micro siting.

Figure 3. View of Kitka terrain where turbines are mounted (photo taken before mounting)

Site consists of 7 units of GE3.6 MW turbines and 3 units of GE3.2 MW turbines, as shown in Figure 4. Turbines are located regarding wind potential, site accessibility, public land usage and private land usage. Same as in Koznica case, there also is tended to save the distance of 3D distance between them. In the case of Kitka since we have a change in the capacity of the turbines, looking at Figure 4 it may seem that 3D distance is not saved here. But even here this distance is maintained, but since the capacity changes then their diameter also changes as is presented in Table 2, when we have 3.6 MW and 3.2MW. The wind farm consists of 7 units of GE 3.6 MW turbines and 3 units of GE 3.2 MW turbines where the positions of them is presented in Table 3. The turbines are located regarding wind potential, site accessibility, public land usage and private land usage.

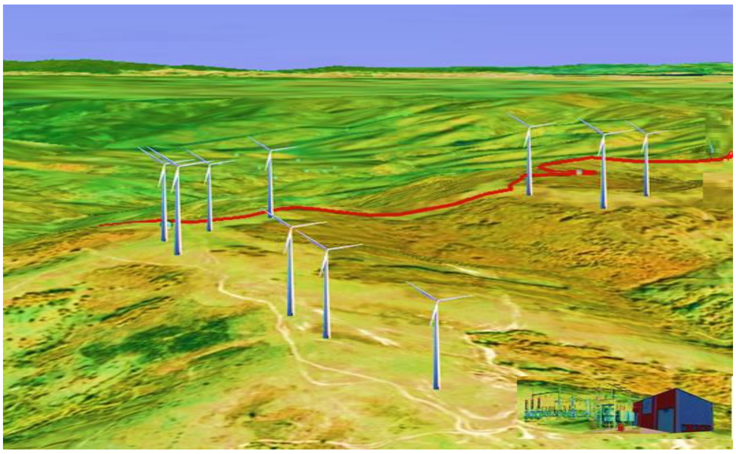

Figure 4. 10 wind turbines in Kitka wind park

Table 2. Turbine layout summary, used in Kitka wind farm

Turbine type	7 x GE 3.6-137 3 x GE 3.2-130
Hub height	110 m
Rated power	3600 kW & 3200 kW
Number of turbines	10
Installed capacity	34.8 MW

Table 3. Placement of wind turbines and coordinates for wind farm in Kitka

Turbine No.	X	Y	Level above sea (m)
T1	544918	4726483	966.6
T2	545205	4725695	1000.0
T3	546034	1726525	1039.0
T4	546423	4726094	1019.9
T5	546741	4725671	1090.0
T6	547076	4725999	1060.0
T7	547427	4726226	1031.8
T8	546545	4724341	1070.0
T9	546878	4723993	1080.0
T10	547258	4724234	1040.0

2.3. Basis for comparison between the two locations

From the data presented and those measured in the field, some comparisons can be made for the two wind parks, as:

- Comparison of the change in wind speed over the months
- Comparison of altitude for each turbine in the two wind parks
- Comparison of the level of the terrain roughness index
- Comparison of horizontal distance between the wind turbines in the respective parks

Duration of minimum wind speed needed to start wind turbine and maximum wind speed is also presented for two locations.

3. RESULTS AND DISCUSSION

The diagrams in the following figures present comparison of several important parameters between the two locations. The diagram in Figure 5 presents mean wind speed for two locations measured in same height, 84m. As we can see, in Figure 5, as mean wind speed is higher in Kitka, also for different months in Kitka, wind speed is higher. In the same figure we presented the wind direction for Kitka and Koznica for one year measurement in those locations. In the other part, In Figures 6 (a)-(b) we presented the wind direction for Kitka and Koznica for one year measurement in those locations, where a is for Kitka and b for Koznica. The predominant direction can be seen to be mainly from the south-east, for both wind farms.

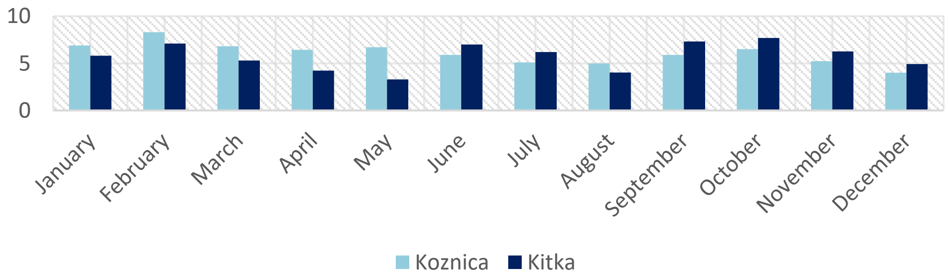

Figure 5. Comparison of Kitka and Koznica mountains monthly wind speed

(a) (b)

Figure 6. Comparison of Kitka and Koznica mountains wind direction, (a) Kitka and (b) Koznica

Wind direction is an element that must be taken into consideration in comparison to a large extent and especially for real installation. To accurately assess the direction of the wind in a place we need measurements of at least one year. Elevation is also of high importance, as can be seen in Figure 6, altitude is higher in Koznica, and in turbines T8 and T9.

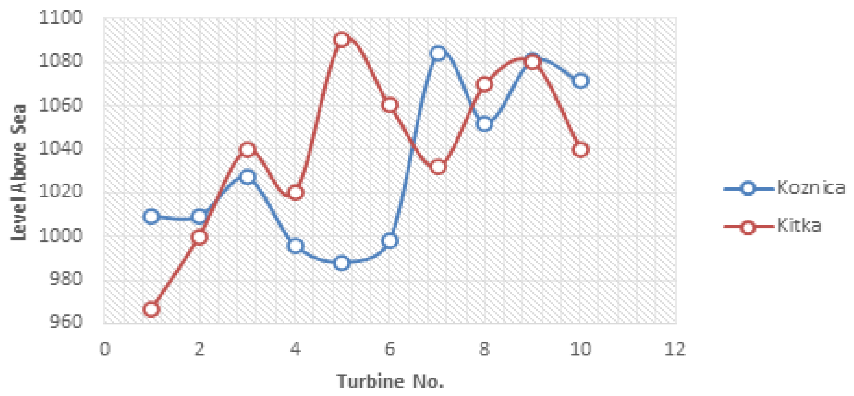

Figure 7. Comparison between the altitude at which the wind turbines are installed

The ruggedness index (RIX) is described in detail in Bowen (1996), Mortensen (1997), and Bowen (2004). The following conclusions regarding RIX can be made:

- If the RIX is close to zero, then the terrain is generally less steep then 0.3 and the airflow in the region is likely to be attached.
- If the RIX is greater than zero, then parts of the terrain are steeper than 0.3 and flow separation may occur in some sectors [27], [28].

dRIX is the orographic performance indicator.

$$dRIX = RIX_{WTG} RIXmet, mast$$

Those indicator relationships are described in Figure 7 for Kitka and Koznica, and as we show in diagram. For Kitka as dRIX values between met mast and turbine locations are in the range of 2 – 8%, similarity principle can be said to be mostly achieved. For Koznica it can be concluded that the prediction of production for wind turbines 1- 8 is generally acceptable, while for the turbine 9 and 10 the uncertainty in the estimation of production is significantly higher because dRIX for turbine 9 is 8 %, and for turbine 10 it is 11 %. In addition, the turbines 8, 9 and 10 are located at about 4 km of the measuring mast, so the estimation of potential in these locations is with significant uncertainty.

From what we can see from the installation of wind turbines for both parks, referred to as Kitka and Koznica, it follows that the turbines T1 and T2 have the larger distance compared with other turbines in Kitka and same turbines T7 and in Koznica, and when we compare energy production those distances are very interested in wind turbines interaction and total energy production.

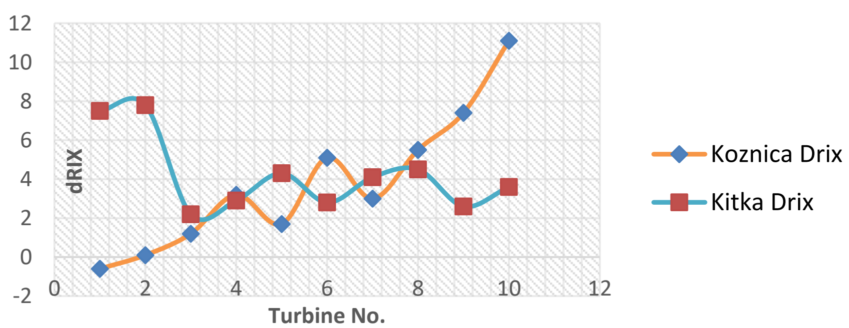

Figure 8. Relationship between RIX and dRIX, for Koznica and Kitka wind parks

4. CONCLUSIONS

The part that is currently operating as a wind park, Kitka is located on the eastern side of Kosovo and also the site where measurements were made in that part, namely Koznica. The analysis shows that Kitka has a dRIX bigger than Koznica, but even this harshness of terrain has not affected the overall potential energy production as much as the wind speed, due to the shape of the terrain that enables it. Many times, in the case of practical realization when we are dealing with the same terrains, as in this mountainous case and when approximately the wind blows in one direction, RIX are taken the same. From this analysis we can conclude that this approach should not be such. Regarding the efficiency of the turbines used, it depends largely on the wind speed, but the height of the turbines is an important factor as well, due to the velocity change with height. Calculations show that turbines have the highest efficiency, as expected, at Kitka, due to the higher wind speeds. On the other hand, as mentioned above, there were two different types of capacity turbines, 3.2 MW and 3.6 MW. An element that has an impact on the overall power generation is the distance between the turbines. For stable operating conditions, it is necessary for them to stay in 3·D distances. If we consider that the turbines will be in operation for 5000 hours during the year, then this will result in annual production of about: 55829.4 MWh at Koznica, and 55019.873 MWh at Kitka wind park, and totally 110.849 GWh. The difference of energy production from those two wind farms is 809.527 MWh. According to data from the Energy Regulatory Office of Kosovo, it follows that the annual average of energy used in Kosovo is 5835000 GWh/year, so by using those wind farms, we will have 0.0018% of electrical energy generated by those two wind farms.

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