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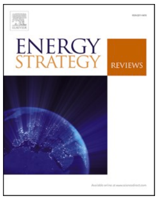

Wind energy potential for the electricity production - Knjaževac Municipality case study (Serbia)

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ABSTRACT

Geospatial potential for harvesting wind energy is not an easy task to perform in conditions of deficiency of accurate data in remote and large areas (macro to medium locations). There are different methodologies available to identify the most suitable location for the installation of wind power generators. One of the most suitable approaches that employ the Multi-Criteria Analysis method for wind energy potential of the Municipality of Knjaževac (East Serbia) is combining the Analytic Hierarchy Process (AHP) and Geographic Information Systems. Collection and creation of geospatial data for the research encompassed meteorological data from all available sources, digital elevation model (DEM) to analyze the orography of the terrain, and Landsat 8 satellite data to analyze six land cover (LC) classes. The identification of three best locations for the wind power generators (wind farms) using Multi-Criteria Decision Making (MCDM) analysis solved the major location problem: how to select the best locations for investment in the renewable energy sector and minimize the impact on the environment. The result indicates that only one part of the municipality, at the hub height of 100 m, has enough wind potential to produce energy.

1. Introduction

The global energy crisis, as well as local, has increasing tendency since the beginning of the oil crisis of the seventies in the last century, together with higher energy demands, which are caused by fast economic development and urbanization worldwide. Altogether, they spurred the efforts towards the development of wind power as an alternative source of energy. Nowadays, the traditional energy resources are directly in inverse ratio with continuously increasing energy demands that are in line with growing economic activities and urban population. Therefore, the alternative energy resources (hydro-energy, solar, the wind, geothermal, the energy of tide and low tide, biomass, and others) represent a great potential as a solution for solving the energy crisis. Their great advantage in comparison with other energy sources is that they are renewable and in balance with nature and sustainable development.

Wind power is the most abundant renewable energy source in the world, with an average increase per year (28.56%) of installed capacity (1993–2001) and an ongoing growing annual rate (36%) in the following several years. For the period 1999–2005, the increase of the wind generator installation capacity in the world was more than four times [1]. The worldwide wind capacity reached 336 GW by the end of June 2014 [2], while in 2018, cumulative wind power capacity reached a value of 651 GW [3]. Therefore, the wind energy sector has the most significant growth market compared to all other resources.

Energy production using wind power is in constant expansion since 1985. The largest installed capacity in the world until 2007 was in Europe (69%) [1]. The capacity of installed and grid-connected wind power plants in 2017 in the European Union (EU) was 16,800 MW (which is a 25% increase compared to 2016 installations), with a total net installed capacity of 168.7 GW. The cumulative capacity of wind energy in EU candidate countries (Serbia is one of them) in 2016 and 2017 is 6138 and 6912 MW, respectively. In Europe (EU countries, candidate countries, EFTA, and others – 39 countries) in 2016 and 2017, the cumulative wind energy capacity is 161,342 and 177,506 MW, respectively [4]. Cumulative capacity for the EU in 2019 was 192,231 MW, whereas the non-EU countries in Europe have 12,583 MW, with a total of 204,814 MW for Europe [5]. In 2019, global cumulative wind power capacity was up to 651 GW with 60,400 MW of new installations included, where onshore market with 54,200 MW installations is 17%

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Table 1
Cumulative wind power capacity in EU - most contributing countries, above 5000 MW [4,5,11].

	Cumulative capacity by the end of 2016	Cumulative capacity by the end of 2017	Cumulative capacity by the end of 2018	Cumulative capacity by the end of 2019
Portugal	5316	5316	5380	5437
Denmark	5230	5476	5758	6128
Poland	5807	5848	5864	5917
Sweden	6494	6691	7407	8985
Italy	9227	9479	9958	10,512
France	12,065	13,759	15,309	16,646
UK	14,602	18,872	20,970	23,515
Spain	23,075	23,170	23,494	25,808
Germany	50,019	56,132	59,311	61,357

increased compared to 2018 [3].

According to the 2015 data, China is the World leader with 145,104 MW installed capacity, followed by the EU (141,579 MW), the USA (74,472 MW), and other countries. The wind energy production installed capacity in EU is mostly contributed by Germany (2004/16,629 MW, 2017/56,132 MW, 2019/61,357 MW), Spain (2004/8263 MW, 2017/23,170 MW, 2019/25,808 MW), UK, France, Italy (Table 1) [5]. One of the biggest wind power plants in the World is Gansu Wind Farm (onshore) in China (6000 MW), Alta Wind Energy Center (onshore) in the USA (1547 MW), Fântânele-Cogealac Wind (offshore) in Romania, EU (600 MW) [6–8]. Asia Pacific region in the onshore market is ranked as first in 2019 with 27.3 GW installations. In 2019 Europe had 30% growth (highest in Spain, Sweden, and Greece) despite Germany's 55% less onshore installations [3].

European Environment Agency-EEA forecasted in its official report that the potential wind energy could supply Europe with electric energy and that it could produce three times more energy than it would be European needs by 2020. By 2030, the forecast predicts that the potential produced electric energy could be up to seven times more than required by that time [9]. European Wind Energy Association - EWEA estimates that the wind energy capacity production in Europe that will be installed by 2020 is 230 GW, 190 GW onshore and 40 GW at sea [10].

The use of wind energy potential in Serbia is almost negligible, even though Serbia has significant potential. Some improvement in wind power installation capacity is evident in 2018 (Table 2). However, the application of all research studies of potential wind energy areas that are performed together with investment planning could change the current

Table 2
Wind power installed capacity in region countries (in MW) [4,5,11].

Country	Installed in 2016	Cumulative capacity by the end of 2016	Installed in 2017	Cumulative capacity by the end of 2017	Installed in 2018	Cumulative capacity by the end of 2018	Installed in 2019	Cumulative capacity by the end of 2019
Bosnia and Herzegovina	N/A	N/A	N/A	N/A	51	51	36	87
Bulgaria	0	691.2	0	691.2	0	691.2	0	691.2
Croatia	79	466	147	613	0	583	69	652
Montenegro	N/A	N/A	N/A	N/A	46	118	0	118
North Macedonia	0	37	0	37	0	37	0	37
Hungary	0	329	0	329	0	329	0	329
Romania	48	3024	5	3029	0	3029	0	3029
Serbia	0	10	8	18	356	374	0	374

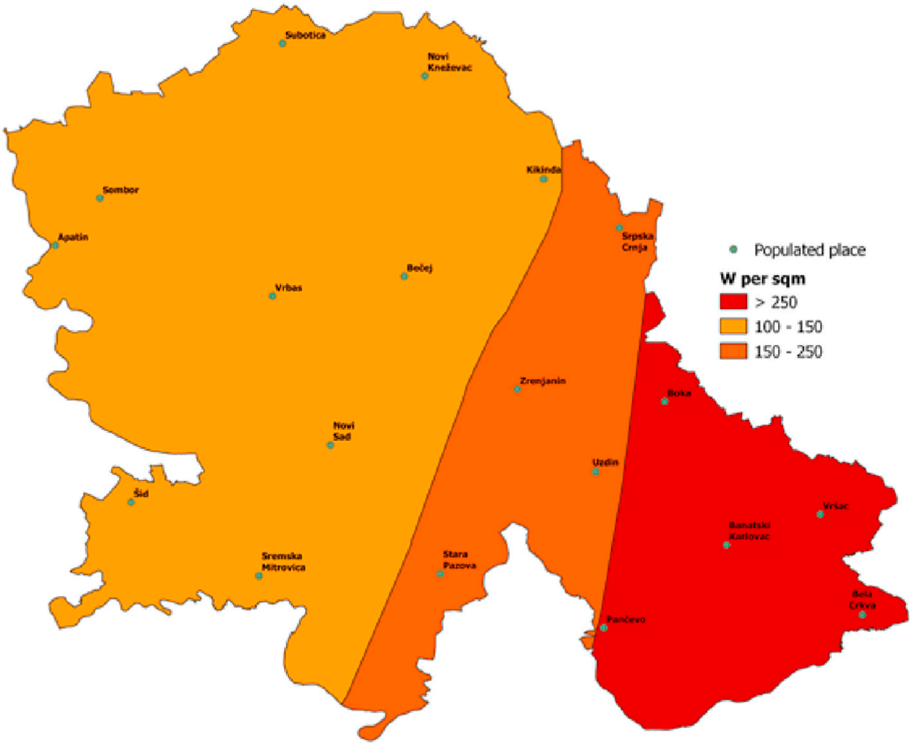

Fig. 1. The average annual density of wind power in Vojvodina [13].

situation.

Table 3
Wind energy permits issued until 08.2019 [15].

No.	Name	kW	Year
1	Devreč 1	500	2012
2	Nova Vrška Čuka	7500	2012
3	Nova Vrška Čuka 1	9950	2012
4	Nova Vrška Čuka 2A	9000	2012
5	Nova Vrška Čuka 2B	9000	2012
6	Kula	9900	2014
7	La Piccolina	6600	2014
8	Alibunar	42000	2015
9	Malibunar	8000	2015
10	Plandište 1	102000	2015
11	Kovačica	104500	2015
12	Čibuk 1	158460	2015
13	Košava	68000	2015
14	Dolovo 1	9900	2018
15	Wellbury- Bela Anta	120750	2018
16	Kostolac	66000	2019

1.1. *Wind power research and electricity production in Serbia*

The leader in the installation of wind power capacity in Serbia's neighbouring countries is Romania, with 3029 MW installed by the end of 2017 [4,5,11] (Table 2).

Extensive research on wind energy potential in Serbia started in 2002. The first completed study on the wind energy potential was for the needs of the Electric Power Industry of Serbia (EPS) in 2002, with very detailed long-time measurements from 20 meteorological stations which gave very detailed results and conclusions that Serbia has significant wind energy potential [12].

In 2005, the Serbian Government made changes in energy policy and development strategy, promoting the advantage of new renewable energy resources in contrast to the experienced energy crisis. That strategy produced the research Study *Wind Atlas of Serbia*. The recording of wind parameters up to a 50 m height of the ground took 18–24 months. The project *Wind Atlas* is completed for Vojvodina (north part of Serbia) (Fig. 1), and still have to be completed for the rest of the country. As advised by the Ministry of Mining and Energy, researched sites would be profitable for investment in wind farms if the slowest annual wind speed were within the range of 4.9–5.8 m/s. According to the *Study,* Pannonia lowland, East Serbia, and the mountains in West Serbia (Zlatibor, Kopaonik, Divčibare) have the best wind energy potential [14].

In 2011, 16 potential locations were analyzed. Studies have shown that Serbia could produce half of the present annual production of primary energy from renewable energy resources, including wind power [13]. The wind energy and small hydropower plants are the best cost-effective alternative energy resources. In general, it was stated that the most significant wind energy potential areas are in Vojvodina (North Serbia) and East Serbia (where the Municipality of Knjaževac is located) [14].

There are not many wind power plants in Serbia. The built permits issued by the Ministry of Mining and Energy are in Table 3. The first Serbian wind farm was built near the city of Kula in 2015. In 2016 *La*

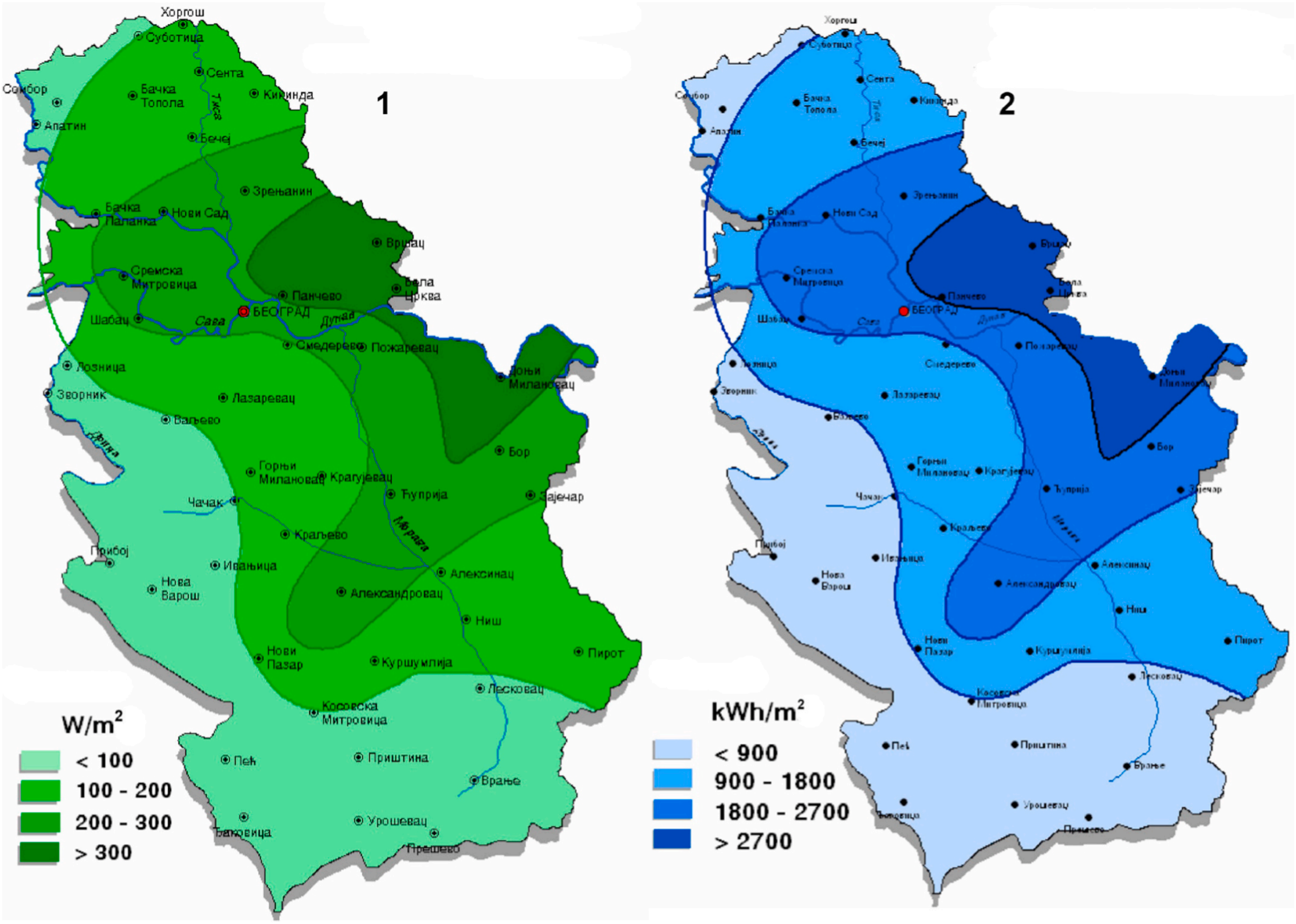

Fig. 2. The average annual wind power (1) and energy (2) in Serbia [16].

Table 4
Wind speed measurements for tree locations (wind Košava area) in Serbia at a hub height of 50 m [13].

Location	Average wind speed (h = 50 m) m/s	
	6 month	12 month
Veliko Gradište	3.61	3.5
Negotin	5.24	5.77
Titel	4.68	4.72

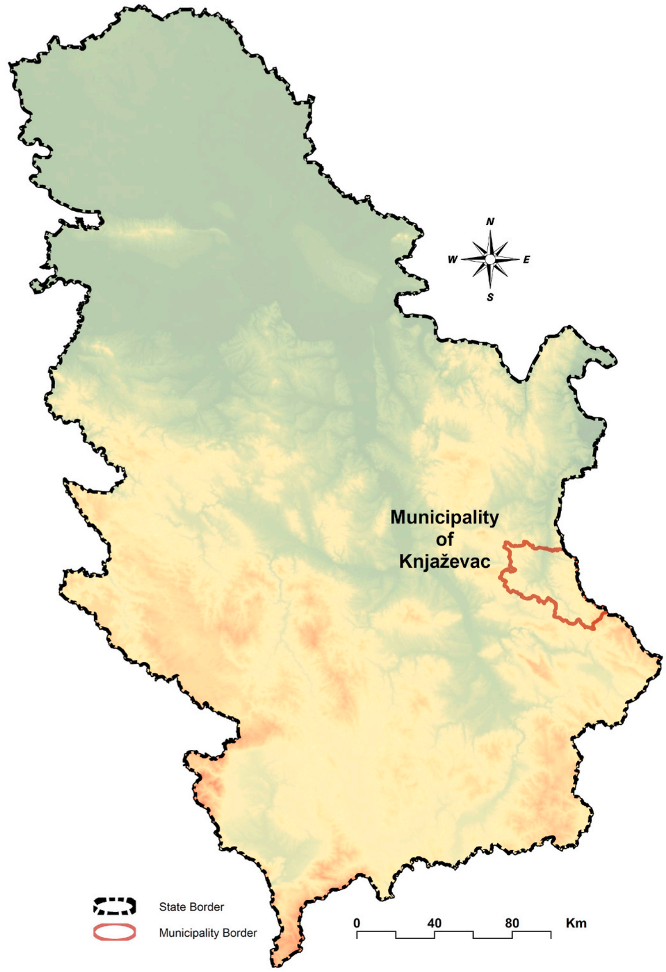

Fig. 3. Location of the Knjaževac municipality [18].

Piccolina wind park near the town of Vršac has been constructed. The location of wind farm Čibuk is in Vojvodina, in Kovin municipality.

Fig. 2 shows that there is substantial wind potential in Serbia, so this paper aims to identify the most appropriate macro sites for the installation of a wind power plant in Knjaževac Municipality.

As can be seen from Tables 2–4, the wind power plants focus in Serbia is mainly on Vojvodina (wind Košava area). The south part of the country is neglected so far.

One of the most crucial documents dealing with renewable energy sources in this underdeveloped part of Serbia is the Regional development strategy of the Timok region for the period [17]. This strategy, which also includes the area of interest, Knjaževac municipality, specifies that there are no installed wind turbines within 150 km, although there is potential for their installation. The average wind energy for the region is 150 do 375 kWh/m^2 in winter part of the year and 75 kWh/m^2 during summer [17].

The area of Knjaževac municipality is part of the Timok region and located in East Serbia (Fig. 3). The total area of interest is 1201.8 km^2. The altitude is significant and extends between 169 m and 2067 m. The lowest attitude is in the northern-central part and the highest in the southeast part of the area (Fig. 4). Continental, moderate-continental, and mountain climate are disseminated in Knjaževac Municipality [18] (Fig. 4).

1.2. *Climate types in Serbia*

Serbia is located in the continental climate region where are present: the continental climate in the lowlands (up to 800 m), the moderate-continental climate in lower parts of the mountain region (800–1400 m) and the mountain climate on high mountains (over 1400 m). The primary influence on the climate in Serbia originates from air masses formed over the Arctic, Siberia, Atlantic Ocean, Mediterranean, and the African Sahara, where the high air pressure field is formed. The cold air penetrates mostly from the Siberia but rarely from the Arctic [19]. North part of Serbia is vast Panonic lowland located north from the rivers Sava and Danube. These rivers divide Balkan Serbia from Middle Europe and its entirely different landscape. Panonic Serbia is wide open and exposed to the climate influences that spread from the north, west, and east. Continental climate, which extends over the Panonic lowland, encompasses Vojvodina and Central Serbia up to 800 m. Extremely hot summers with insufficient humidity, long and severe winters, and mild and short autumns and springs are the main characteristics of the continental climate [20]. Mean annual air temperatures in the Panonic area are increasing from the west toward the east and from the north to the south [19]. This climate type extends over the lowest, central part of the Knjaževac Municipality and occupies the area of 950.45 km^2 (79.08% of the municipality) (Fig. 4). Primary climate influence takes effect through the river Timok valley that is wide open to the north.

Regions between 800 and 1400 m belong to a moderate-continental climate. Summers are moderately hot, and autumns are longer and hotter than springs, while winters are cold [19]. This climate type extends over the peripheral part of the Knjaževac Municipality and occupies the area of 230.42 km^2 (19.17%) (Fig. 4) and covers middle and higher mountains reaching the Knjaževac basin.

Mountain climate covers the range above 1400 m. The main characteristics of this climate type are long, cold, and snowy winters, and short and chilly summers [20]. This climate type extends over the mountainous, east part of the Knjaževac Municipality and occupies the area of 20.936 km^2 (1.74%) (Figs. 4 and 6-1).

1.3. *MCDM literature review*

When the decision must be made, a different set of information, values, alternatives, and preferences must be available. Identifying alternatives, choosing between them, and finding the best solution is the biggest problem for decision-makers [21]. Renewable energy planning processes are using various MCDM methods [22], which are following some similar steps to fulfil the task: problem definition, identification of alternatives, criteria selection, preparation of the decision matrix and

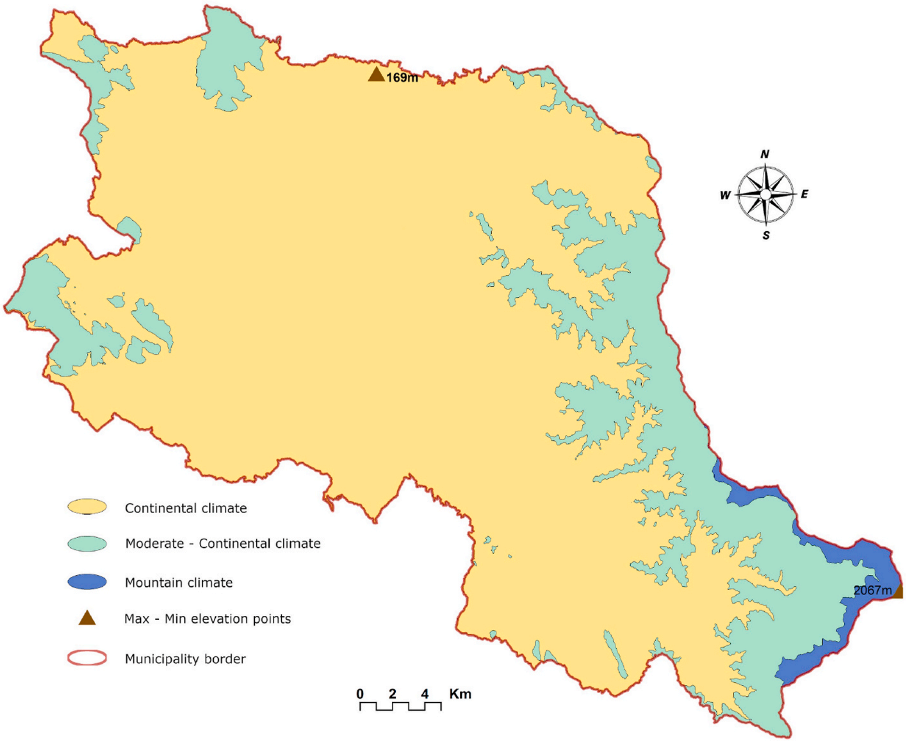

Fig. 4. Climate zones of the Knjaževac Municipality [18].

Table 5
Additional Windfarm site selection studies.

Scientific Research	Technique	Research area
Baban & Parry [41]	AHP&GIS	Lancashire and Yorkshire, UK
Hansen [42]	WLC & GIS	Northern Jutland, Denmark
Rodman & Meentemeyer [43]	Rule based GIS	Northern California, USA
Bennui et al. [44]	AHP&GIS	Thailand
Ramirez-Rosado et al. [45]	AHP&GIS	La Rioja, Spain
Aydin et al. [46]	MCDM & GIS	Western Turkey
Janke [47]	GIS	Colorado, USA
Tegou et al. [48]	AHP&GIS	Lesvos island, Greece
van Haaren & Fthenakis [49]	GIS	New York State, USA
Georgiou et al. [50]	AHP&GIS	Larnaca District, Cyprus
Gorsevski et al. [51]	WLC&GIS	Northwest Ohio, USA
Sánchez-Lozano et al. [52,53]	ELECTRE - TRI & GIS	Region of Murcia, Spain
Schallenberg-Rodriguez et al. [54]	GIS	Canary Islands, Spain
Latinopoulos & Kechagia [55]	AHP&GIS	Regional Unit of Kozani, Greece
Watson & Hudson [56]	AHP&GIS	South Central England, UK
Höfer et al. [57]	AHP&GIS	Städteregion Aachen, Germany

assigning the weights to criteria [23]. In the analysis of energy policies, many different MCDMs can be used [24], such as ELECTRE (Elimination Et Choix Traduisant la Realité), PROMETHEE (the Preference Ranking Organization Method for Enrichment Evaluation), AHP (the Analytic Hierarchy Process) [25]. ELECTRE TRI was used by Silva et al. [26] to categorize alternative site's suitability as low, medium, or high. AHP was used to select available locations for biomass plants [27] and solar power plants [18], as well as for location determination of bioenergy facility [28]. Saaty's analytic hierarchies with the complementary usage of GIS were used by Perpiña et al. [29] to reveal the best alternatives. To determine the best location for a photovoltaic solar farm, Sánchez-Lozano et al. [30] compared TOPSIS, ELECTRE TRI, and AHP. Since there were some potential wind farm locations available and several qualitative and quantitative criteria, the fuzzy AHP and fuzzy TOPSIS were utilized to acquire the criteria weights and locations [31]. Furthermore, the AHP method was exploited to determine the locations of the solar-wind hybrid power plant due to its practicability [32] and solar power plant because AHP values the subjective experience and knowledge [18]. Cebi et al. [33] used a fuzzy set, AHP, opinion aggregation method, and information axiom method as an integrated model to obtain the optimal location for a biomass power plant. Metaheuristic algorithms are also used to specify the optimal locations. For the biomass power plant location, BHBF (Binary Honey Bee Foraging) was used and compared with the results from BPSO (Binary Particle Swarm

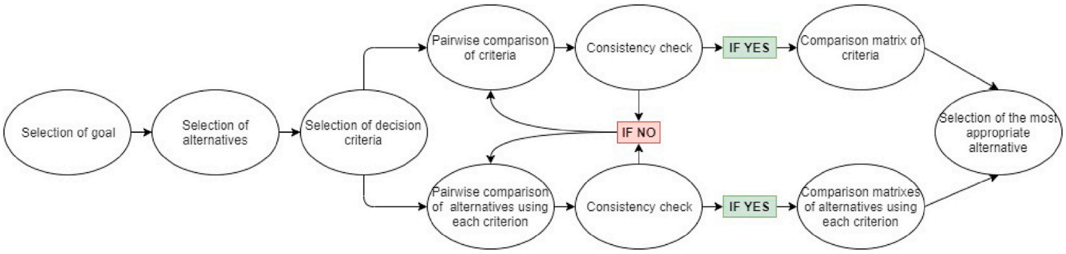

Fig. 5. AHP operation mode [58].

Table 6
Criteria, factors, and indicators.

Criteria	Factors	Indicators	Factor Weight type	Factor Weight (%)
Climate	1. Annual Energy Output		Including	30
	2. Wind Power Output		Including	30
	3. Wind Power Density		Including	20
Location	4. Distance to an urban area (Km)	0–30 km	Including	7
	5. Distance to the road (Km)		Including	4
Orography	6. Grade (°)	<5 5–8.9 9–11.9	Including	3
		12–24.9 >25	Excluding	0
Land cover	7. Urban area 8. Coniferous forest 9. Deciduous forest 10. Arable land		Excluding	0
	11. Pasture 12. Bare soil		Including	6

Optimization) and Genetic Algorithm [34]. Also, the Lagrangian relaxation-based heuristic algorithm was used but further enhanced using the branch and bound structure [35]. Researchers propose different mathematical approaches to locational problems. Bojić et al. [36] provided a mathematical model for the power plant location solution. MILP (Mixed Integer Linear Programming) model was used to obtain an optimal location for biomass power plants [37–40].

Site selection studies for wind farm installations are fairly spread among researchers, as presented in Table 5.

As can be seen from the literature review, it is evident that the decision to select a power plant site is a robust procedure. The researchers use different methods, and all of them have advantages and disadvantages. Finally, MCDM method AHP along with GIS, is chosen because of the possibility to process a large number of input parameters and evaluate all of the possibilities.

2. Materials and methods

The MCDM method used in this paper is the combination of GIS and AHP (Fig. 5). Several different input vector datasets were rasterized and then utilized in the open-source QGIS plugin Easy AHP, which provides Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC) analysis in QGIS [59].

Criteria, factors, and indicators used in the MCDM process to calculate the best locations for wind power harvesting are shown in Table 6. Factor weight type indicates whether the factor completely excludes the area from processing, or it has a particular weight (Factor weight %) to process.

Considering all data contain a geospatial component, QGIS software

Table 9
Water vapour for selected meteorological stations [64,65].

Met. Station	Average Water Vapour (Pascal)					
	2010	2011	2012	2013	2014	2010–2014
Aleksinac	1250	1210	1220	1220	1330	1246
Babin Zub	/	/	/	/	/	/
Bela Palanka	1150	1030	1060	1140	1200	1116
Bunar	1260	1180	1200	960	1350	1190
Zaječar	1150	1020	1010	1010	1130	1064
Knjaževac	1190	1110	1120	1180	1280	1176
Niš	1160	1030	1010	1050	1140	1078
Pirot	1130	1020	1150	1100	1180	1116
RC Niš	1020	910	870	950	1030	956
Sokobanja	1200	1050	1310	1160	1220	1188
Dimitrovgrad	1100	980	980	1010	1090	1032

Table 7
Wind Speed for selected meteorological stations (10 m) [64,65].

Met. Station	Average Wind Speed h = 10 m (m/s)						Average Wind Speed h = 100 m (m/s)
	2010	2011	2012	2013	2014	2010–2014	2010–2014
Aleksinac	1.045833	0.63125	0.642813	0.653125	0.608333	0.716270833	1.273729675
Babin Zub	1.745	1.658333333	1.583333	1.433333	1.316667	1.54	2.933059804
Bela Palanka	/	/	/	/	/	/	/
Bunar	2.442708	1.242708333	1.709375	1.45375	1.409375	1.658697917	2.949628353
Dimitrovgrad	2.475	2.509375	2.394792	2.519792	2.445833	2.468958333	4.390497768
Knjaževac	1.795833	1.876041667	1.680208	1.598958	1.44375	1.678958333	2.985657034
Niš	1.531042	1.386458333	1.551042	1.451042	1.679167	1.51975	2.702540133
Pirot	1.708333	1.590625	1.334375	1.266667	1.253125	1.430625	2.374246519
RC Niš	2.6335	2.6625	2.607292	2.964583	2.539773	2.723697917	4.316770286
Sokobanja	3.539583	2.871875	3.034375	3.241667	2.769792	3.091458333	5.130543775
Zaječar	1.885417	1.864583333	1.975	1.865625	1.74375	1.866875	3.319825374

Table 8
Temperature for selected meteorological stations [64,65].

Met. Station	Average Temperature (K)					
	2010	2011	2012	2013	2014	2010–2014
Aleksinac	286.15	285.65	286.55	286.75	286.75	286.37
Babin Zub	280.95	278.85	279.45	279.05	279.55	279.57
Bela Palanka	285.05	284.15	285.15	285.15	285.25	284.95
Bunar	284.85	284.65	285.35	285.95	285.45	285.25
Dimitrovgrad	284.05	283.35	284.35	284.35	284.35	284.09
Knjaževac	284.55	284.55	285.35	285.25	285.25	284.99
Niš	285.95	285.35	286.25	286.45	286.25	286.05
Pirot	285.35	284.85	285.95	286.15	285.95	285.65
RC Niš	282.35	282.15	283.05	283.15	282.75	282.69
Sokobanja	284.45	283.65	284.95	285.15	285.05	284.65
Zaječar	284.35	284.35	284.85	284.95	284.55	284.61

Table 10
Air pressure for selected meteorological stations [64,65].

Met. Station	Average Air Pressure (Pascal)					
	2010	2011	2012	2013	2014	2010–2014
Aleksinac	/	/	/	/	/	/
Babin Zub	101425.7	103860	103350	104000	101750	102877
Bela Palanka	/	/	/	/	/	/
Bunar	/	/	/	/	/	/
Zaječar	99760	100190	99970	99930	99970	99964
Knjaževac	98000	98390	98200	98130	98150	98174
Niš	92050	99440	99240	99180	99190	97820
Pirot	/	/	/	/	/	/
RC Niš	92050	92440	92270	92230	92250	92248
Sokobanja	/	/	/	/	/	/
Dimitrovgrad	96160	96570	96390	96340	96350	96362

Table 11
Hellmann exponent values for Serbia [16].

Class	Value	Location description
1	0.18	Stations on mountain tops
2	0.20	Coastal stations and stations in the highlands and folds
3	0.22	Airports, suburb stations in plain regions
4	0.25	Urban stations and stations at hilly surfaces
5	0.28	Stations located in valleys

and Easy AHP plugin are employed to analyze the area for best wind farm locations. GIS-based AHP compares each map layer, and determines weight values, combines each other using Weighted Linear Combination to generate a suitability map [59].

Including factors used for research are presented in Table 5. This process requires the factors to be graded in two ways:

1) the decision must be made whether they include or exclude the covered area from the area of interest (Factor Weight type column in Table 5),
2) for the including factor, the weight values (Factor Weight (%) column in Table 6) must be specified.

The area that is marked with any of the excluding factors is masked and excluded from the research. To the remaining area, including factors with assigned weights are applied. Although the overall procedure is objective, the choice of weighting factors is based on the subjectivity of the decision-makers.

Factors in Table 6 are calculated using the presented methods in the following sub-sections.

2.1. Climate-related data

Three starting factors for MCDM analysis are the Annual Energy Output (AEO - preliminary estimate of the performance of a particular wind turbine), Wind Power Output (WPO - the amount of power they can safely produce at a particular wind speed), and Wind Power Density (WPD - a quantitative measure of wind energy available at any location) for the study area (Table 6). Wind power, as stated by de Meij, A. et al. [60], is calculated by adding the instant power of the turbine at each time step for the duration of the Typical Meteorological Year (TMY). They present the energy that can be produced from the wind for each cell (30 × 30 m).

1. *Annual Energy Output* (AEO) can be calculated as shown in Eq. (1) [61]:

$$AEO = 0.01328 * D^2 * V^3 \tag{1}$$

where:

AEO – Annual Energy Output, MWh/year.
D – Rotor diameter, feet^2
V – Annual average wind speed, mph.

2. *Wind Power Output* (WPO) can be calculated using the following formula (Eq. (2)) [61]:

$$WPO = K * Cp * 0.5 * AD * ws^3 \tag{2}$$

where:

WPO – Wind Power Output, kW
k – 0.000133 (a constant that converts the value to kW)
Cp – Maximum power coefficient (range from 0.25 to 0.45, theoretical max = 0.59)[1]
AD - Air Density (kg/m^3)
A – rotor swept area (π*D^2/4)
ws – wind speed.

3. *Wind Power Density* (WPD) at the hub level using industry-standard formula (Eq. (3)) [62], according to ESMAP [63] guidelines.

$$WPD = 0.5 * AD\ ws^3 \tag{3}$$

where:

WPD - Wind Power Density, W/m^2
AD - Air Density (kg/m^3) and
ws – wind speed (m/s).

AD, used in WPO and WPD equations, present the density of the dry air. The density of dry air[2] is used as a standard in the wind industry, and it varies according to the air temperature and pressure (Eq. (4)) [23]:

$$AD = P/Rd * T \tag{4}$$

where:

P - Pressure (Pascals)
Rd - Specific gas constant (J/(kg*degK) = 287.05 for dry air)
T - Temperature (degK).

Since this equation (4) is for dry air, we must calculate the air density affected by the moisture in the air. Following formulas are going to be

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[1] Different types of wind turbines have different maximum theoretical efficiencies (Betz limit ≈0.593) but usually between 0.4 and 0.5.

[2] 1.225 measured in kg/m^3 at standard atmospheric pressure at sea level at 15 °C.

used (Eqs. (5) and (6)) for that calculation [23]:

$$AD_f = (pf / Rd \ * \ T) * (1 - 0.378 \ * \ Pwv / pf) \tag{5}$$

$$Pf = Pda + Pwv \tag{6}$$

where:

AD_f - Air Density (kg/m^3)
Pf - total air pressure (Pascals)
Pda - Pressure of dry air (Pascals)
Pwv - Pressure of water vapour (Pascals)
Rd - Specific gas constant (J/(kg*degK) = 287.05 for dry air)
T - Temperature (degK).

Data used to calculate all climate factors (factors 1, 2, and 3 in Table 6) was collected from the official Meteorological annual [64] and Automated Meteorological Station (AMS) Babin Zub [65]. Collected meteorological data is presented in the following tables: Wind speed is provided in Table 7, Temperature in Table 8, Water vapour in Table 9, and Air pressure in Table 10.

Since the wind speed (ws) data is deficient at default measure height (h = 10 m) (Table 7), potential wind speed at 100 m hub height was calculated using the "power law" model of vertical wind speed profile (Eq. (7)) [66–69] to be used in climate factors equations (1)–(3) (Table 7):

$$V / V_0 = (H / H_0)^{\alpha} \tag{7}$$

where:

V – Wind speed at hub height, m/s (100 m)
V_0 - Wind speed at reference height, m/s (10 m)
H – Hub height (100 m)
H_0 – Reference height 10 m
α - Hellmann exponent (Table 11).

Hellmann's exponent values depend on topographic characteristics, and the coefficient presents the roughness of topography [16]. For Serbia, there are five classes of Hellmann exponent values (Table 11).

Corresponding Hellmann's exponent value was assigned to each of the 11 meteorological stations (Table 7), and then Kriging interpolation geostatistical method applied to the data.

Geostatistical interpolation Ordinary Kriging was applied to the average data for the five years (2010–2014 period) presented in Tables 7–10 to calculate and model all necessary raster data with a 30 m spatial resolution [18].

Ordinary Kriging predictions are based on the model (Eq. (8)) [70]:

$$Z(\mathbf{s}) = \mu + \varepsilon'(\mathbf{s}) \tag{8}$$

where:

μ - the constant stationary function (global mean)
ε' $(\mathbf{s})$ - the spatially correlated stochastic part of the variation.

A value of the target variable at some *new location* can be derived as a weighted average (spatial prediction) (Eq. (9)) [71]:

$$\widehat{\mathscr{Z}}_{\mathrm{OK}}(\mathbf{s}_0) = \sum_{i=1}^{n} w_i(\mathbf{s}_0) \cdot \mathscr{Z}(\mathbf{s}_i) = \lambda_0^{\mathrm{T}} \cdot \mathbf{Z} \tag{9}$$

where:

λ_0 - the vector of kriging weights (w_i),
$\mathbf{z}$ - the vector of n observations at primary locations.

Calculated input parameters for factor calculations are presented in Fig. 6.

2.2. Location-related data

The vicinity of the **4.** urban area and **5.** roads are marked as including factors, and urban areas and roads as land cover are marked as excluding. Urban areas and road locations are mainly collected from multispectral analysis data explained in section 2.4. The vicinity is marked as three zones of 10 km distance (0–10 km, 10–20 km, 20–30 km). An area that is located more than 30 km from the urban areas and roads are not considered.

2.3. Orography

The 30 m ASTER GDEM v2 [72] was adjusted with 987 digitized elevation points from topographic map 1:50,000 [73] and then interpolated (Eq. (9)) [71] to enhance the DEM (Fig. 6-1).

Grade

Enhanced DEM is used to perform Grade analysis of terrain to obtain the slope degrees. Calculated data present a suitable construction area (Fig. 7-1). Terrain with slope values higher than 13°, in general, is not appropriate for any construction (Table 12).

The Grade of the field at a point is defined as the angle measured in the vertical level involving the tangent plane to the surface of the field at a given point in the horizontal plane at the same point [75].

The scale of the usability of terrain for the construction needs is shown in Table 12.

2.4. Land cover

One of the essential criteria for the MCDM to achieve the goal of this paper is the land cover map, which contains six classes (factors **7–12** in Table 6).

Atmospheric and topographic corrections were applied to Landsat 8 satellite data [76] to get the best possible results [77]. The acquisition date of the multispectral bands is May 20, 2015. Pan Sharpening method was used to enhance the quality of satellite data. Classification of the data was performed using a minimum distance algorithm [77] employing the multispectral supervised analysis. The data was classified as following land cover classes: **7.** Urban/Built Area, **8.** Coniferous Forest, **9.** Deciduous Forest, **10.** Arable land, **11.** Pasture/Grass, and **12.** Bare soil (Fig. 7-2 and Table 6). The accuracy of the data was compared using large-scale topographic maps, Orto photo footage, Municipality plans [71,78].

3. Results

The first analysis gave the result of the wind speed at the hub level (10 m) (Fig. 6-2). Since wind speed at the hub level of 10 m has insufficient values for any wind power generation, the analysis was extended to calculate the wind speed at a hub height of 100 m. All the data that was used in MCDM analysis to choose the best location for the wind power farm was classified into adequate classes for the final calculation. The focus was on AEO, WPO, WPD, Grade, and Land Cover data. The wind data focus was on high values, while the grade data focus was on low values. Focus on the Land cover data is as follows: adverse classes are Urban Area, Coniferous Forest, Deciduous Forest, and Arable land; classes Bare soil and Pastures were marked as highly suitable.

The final data calculated from climatologic data show that there are not many potential locations to build a wind farm, and the meteorological derived data (WPD, WPO, and AEO) are in full compliance.

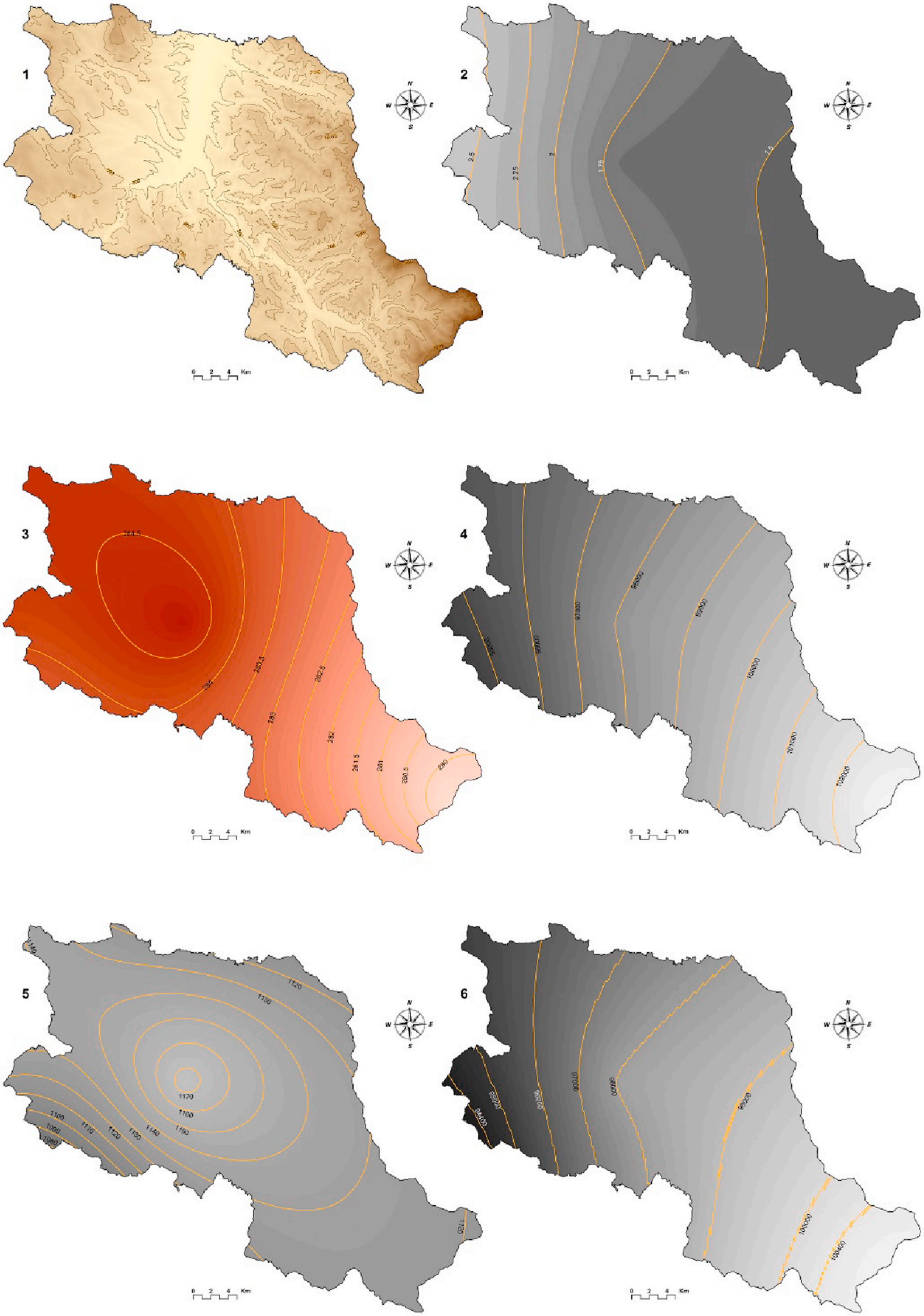

Fig. 6. Raster datasets used for calculations: **1)** DEM (m), **2)** wind speed distribution (m/s), **3)** temperature distribution (K), **4)** air pressure (Pa), **5)** water vapour distribution (Pa) and **6)** air density (kg/m3).

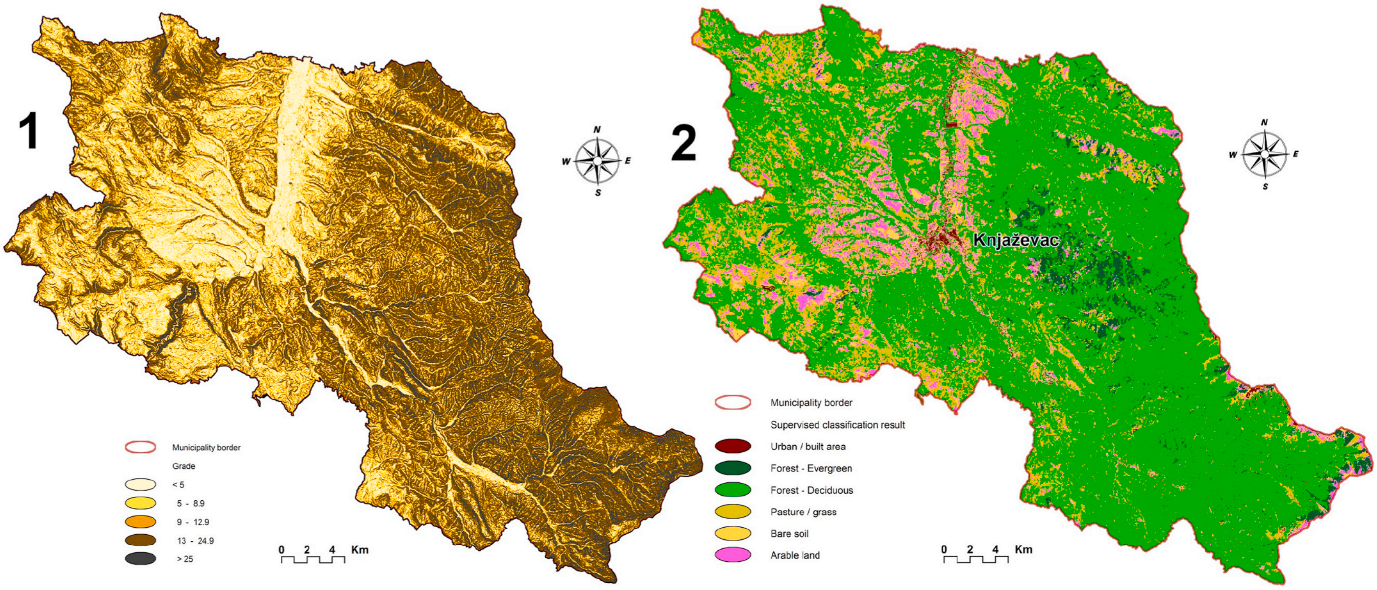

Fig. 7. Knjaževac Municipality Grade (**1**) and Land Cover map (**2**) [18].

Table 12
Grade categories [74].

Grade	Description	Usability
<2°	Plane	Very favourable for construction
2–5°	Slightly sloped terrain	Favourable for construction
5–12°	Sloped terrain	Favourable with landscaping
12–32°	Significantly sloped terrain	Unfavourable, useful for the construction only after major interventions
>32°	Very steep slopes	Unfavourable for construction

Table 13 presents the WPO and AEO data for selected meteorological stations, and Fig. 8 presents the distribution of the AEO data for the Municipality of Knjaževac. As presented in Table 13, the area near Sokobanja meteorological station has the most potential, and, therefore, the western part of the Knjaževac Municipality is the most suitable for energy production using the wind (Figs. 8 and 10). The maximum AEO value for the municipality is 85 MWh/year in the northwest part of the area.

The highest average monthly wind speed is recorded in the winter part of the year, February, March, and April (Fig. 9).

Fig. 10 presents the wind power density (W/m^2) for the municipality. As seen from the results, the highest values are in the western part of the municipality. Compared to the official data that classify the municipality in 100–200 W/m^2 zone (Fig. 2), we can notice that our results present the minimal possible wind power for the researched area. Researched values in the Eastern part of the municipality are much lower, indicating

Table 13
Wind power output and Annual energy output for selected stations.

Station Name	WPO, kW	AEO MWh/y
Aleksinac	2.996036	1.90446378
Babin Zub	36.58289	23.25432143
Bela Palanka	31.1494	19.80046111
Bunar	37.20636	23.65063546
Dimitrovgrad	122.7034	77.99777227
Knjaževac	38.58647	24.52791721
Niš	28.6175	18.19103346
Pirot	19.40406	12.33440904
RC Niš	116.6251	74.13405099
Sokobanja	195.7967	124.4603761
Zaječar	53.04702	33.71992782

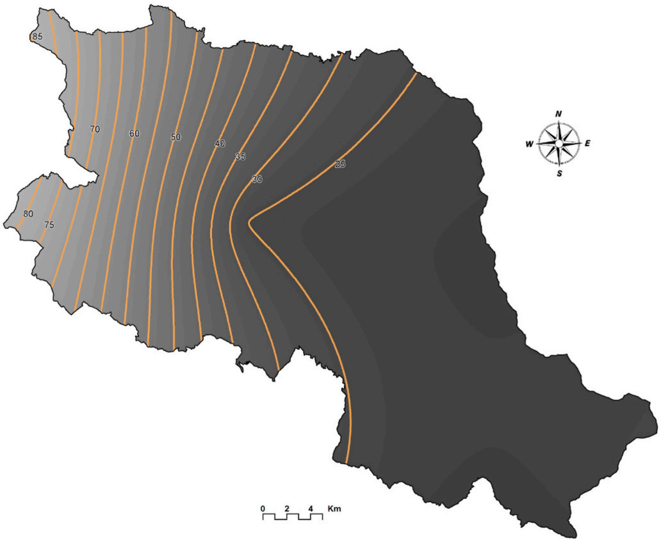

Fig. 8. Knjaževac Municipality AEO map (MWh/year).

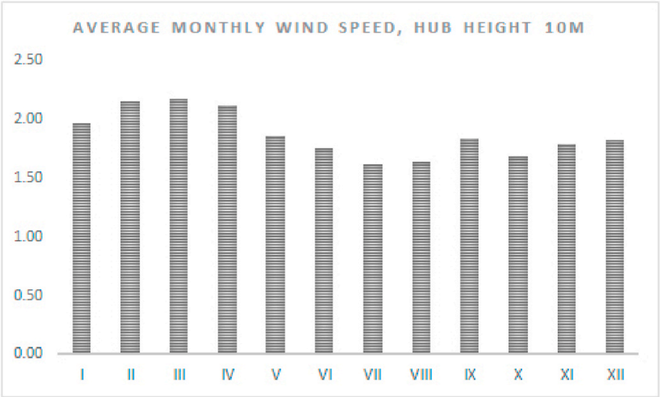

Fig. 9. Average monthly wind speed for the five years (2010–2014) [64].

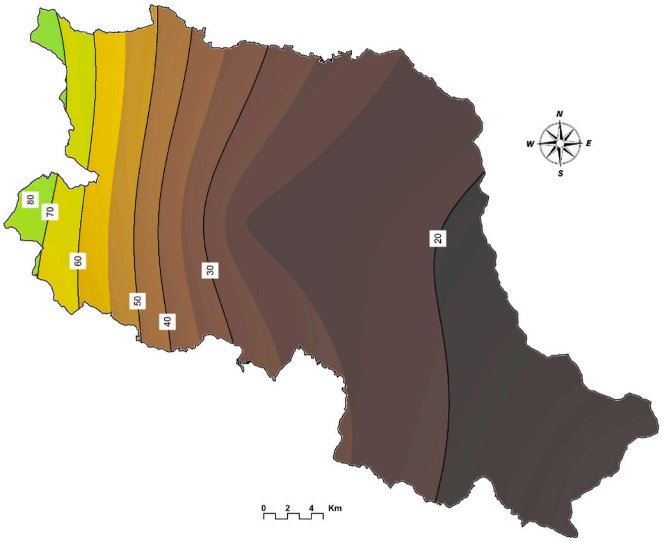

Fig. 10. Knjaževac Municipality WPD map (W/m^2).

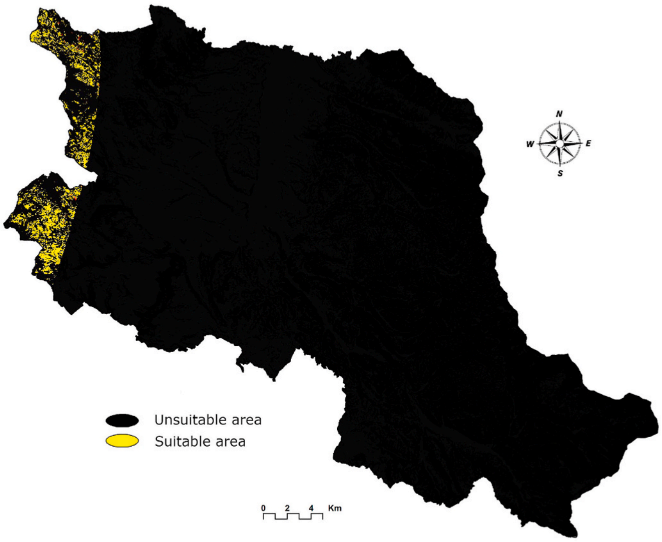

Fig. 11. Knjaževac Municipality wind energy potential MCDM map.

there are no conditions to use wind energy (20 W/m^2).

After applying MCDM analysis, the most suitable locations are calculated in the western part of the Municipality (Fig. 11).

4. Discussion

The values in this paper present the minimal possible energy production since no gust speed was calculated, and therefore, the potential of the area is higher than presented. This method is suitable for dissected relief areas to calculate its potential for clean energy use and sustainable development in cases when a lack of meteorological input data is present due to remote and rugged landscapes. The calculations for climate data for the municipality were performed using available official meteorological data [64]. The divergence between the official State's wind potential data (Fig. 2) and the results obtained in this paper (Fig. 8) is due to the different data processing methods.

The result, three possible locations for the wind power generators in Knjaževac Municipality (Fig. 12) are chosen within the suitable area marked on the Knjaževac Municipality wind energy potential MCDM map (Fig. 11). These three locations are chosen within a suitable area where two including factors (4. Distance to an urban area (Km) and 5. Distance to the road (Km) in Table 6) had a higher factor weight. If the weight factors are changed, decision-makers can find a more suitable location depending on the investment needs.

5. Conclusion

The overall result in Fig. 11 leads to the conclusion that there is a small wind energy potential in the municipality. Compared to other wind energy potential studies in Serbia, this paper presents a new

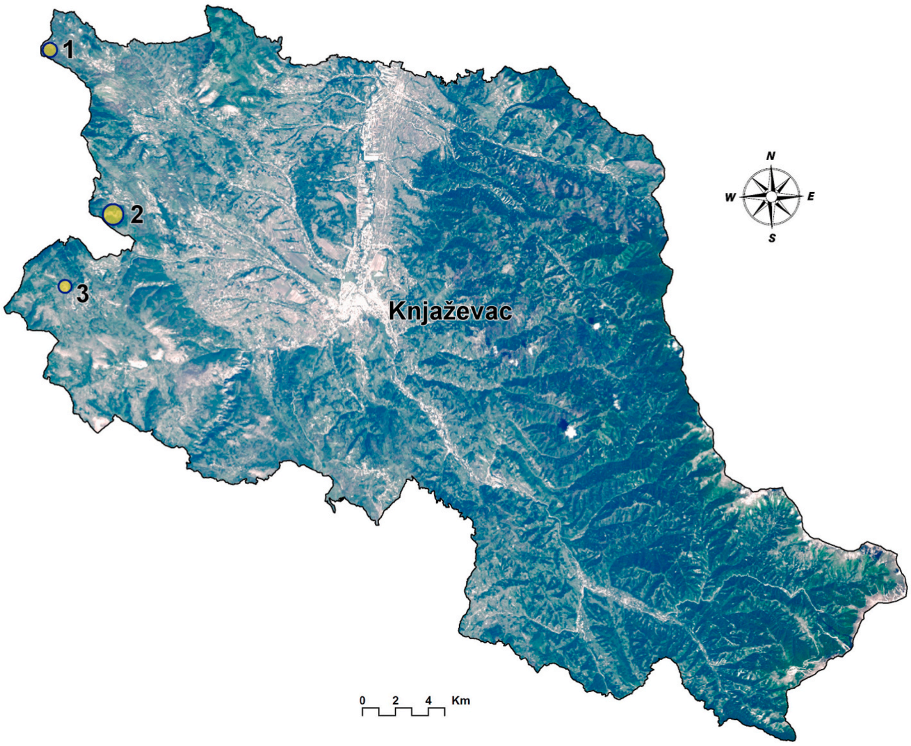

Fig. 12. Knjaževac Municipality wind farm possible locations.

approach to the location selection problem employing widely available open-source MCDM AHP, GIS tools (QGIS), and open data. The explanation of how different criteria based on official and open data were defined to obtain information on potential wind farm locations is the main advantage proposed to decision-makers. In order to obtain a precise classification of land cover, the satellite images of higher spatial resolution should be used. Results from this study provide a general survey and give a good starting insight into the wind potential for the studied area, especially in developing countries with underdeveloped institutions.

Credit author statement

Ivan Potić: Conceptualization, Methodology, Software, Analysis, Quality Assurance; Tatjana Joksimović: Data collection and preparation; Uroš Milinčić: Data collection, Visualization; Dušan Kićović: Data validation, Investigation; Miroljub Milinčić: Validation, Writing-Reviewing and Editing, Quality Assurance.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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