Evaluation of natural conditions for site selection of ground-mounted photovoltaic power plants in Serbia

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Abstract
In recent decades, many countries tend to increase the use of renewable energy sources. Serbia has good natural conditions for the exploitation of solar energy. This paper integrates geographic information system and multi-criteria evaluation approach in order to select the best sites for development of ground-mounted photovoltaic power plants. The spatial suitability index was calculated for the whole territory of Serbia. It is shown that northern part, especially Banat region, possesses the largest potential for development of solar projects. Comparing obtained results with locations of existing photovoltaic power plants in Serbia, certain disagreements were noted. This is due to the application of exclusion criteria that except agricultural land even if the quality of the soil is poor. Beside the geographic distribution of suitable land, this study has shown that the largest electric power generation potentials have the City of Zrenjanin, Municipality of Novi Bečej, and Municipality of Čoka. Potentially, they can generate enough electricity to substitute whole yearly electricity production in Serbia. At the end, the subject of research was focused on the best ranked parcels, showing the potential electricity generation and the inter-annual variability in energy production based on module temperature.

Keywords: solar energy, multi-criteria evaluation, Analytic Hierarchy Process, spatial suitability index, module temperature

1. Introduction

Sun is clean, free, and abundant energy source that could meet growing energy consumption in both developed and developing countries. Use of solar energy ensures the way for social and economic prosperity without environment pollution and impacts on climate change [1]. Many countries around the world are making significant efforts to evaluate their solar potential to formulate better strategic and planning documents, as well as, the incentives. It leads to expansion and sustainable development of the solar energy systems. In order to evaluate spatial suitability and selecting the most favorable areas for development of photovoltaic (PV) systems, it is necessary to collect and prepare certain data for selected criteria. Subsequently, the evaluation process is based on mathematical procedures, which usually require a lot of time and money, especially if they are carried out manually. With the development of multi-criteria evaluation (MCE) methods and Geographic Information System (GIS) it has become easier to obtain an optimal spatial allocation of photovoltaic power plants (PVPPs) [2]. GIS usually has many MCE methods [3]. It is able to handle, processing, and analyzing a large quantity of spatial data [4], and therefore it has become indispensable in many studies. Some authors, like Charabi and Gastli [5] considered the effect of temperature and dust when selecting the sites for large PVPPs using Fuzzy logic and GIS-based spatial MCE. Other authors [2,3,4,6] used Analytical Hierarchy Process (AHP) as common MCE method and more factors that have been classified into criteria groups (climate, location, orography, environment, etc.) to find the best sites for PVPPs. The AHP implemented in GIS environment was also used in this study.

The utilization of solar energy in the Republic of Serbia (hereinafter referred to as Serbia) is still at the beginning, although it is geographically positioned in southeastern Europe. Compared to Central Europe, where many solar plants already exist, the energy potential of solar radiation in Serbia is higher for 30% [7]. According to the International Renewable Energy Agency (IRENA), the estimation of the total installed PV capacity for the year 2015 in Serbia is 6 MW [8]. Northern part of Serbia has the highest values of annual average sunshine hours with ~2200 hours per year [9]. It is not the case for average annual energy from global radiation with a peak of 1550 kWh/m^2/year in the south and southeastern parts of the country [10]. The lowest values of average annual energy from global solar radiation of 1240 kWh/m^2/year are in the northwestern part of Serbia [7]. It is equal to the highest one in Germany which is the second ranked country in the world according to total installed PV capacity of 37.9 GW [11]. So far, the economic situation in Serbia does not allow higher investments in such sophisticated technology. Based only on the currently available capacities of electric power system of Serbia for the provision of tertiary reserves, the maximum technically usable capacity of PVPP was estimated at 450 MW, i.e. their technically usable potential is 540 GWh/year [10]. This requires further research in order to better understand the potentials for development of PVPPs on the territory of Serbia. Pavlović et al. [12] used PVGIS program to calculate the annual sum of global radiation per square meter received by modules of different PV solar plants of 1 MW and their electric generation based on the geographical position for 23 locations in Serbia. In their study, Luković et al. [13] used Potential Incoming Solar Radiation module of SAGA (System for Automated

Geoscientific Analyses) open source GIS software, and digital elevation model with the resolution of 90 m to get high resolution solar radiation maps for Serbia. Recent assessments of spatial suitability for development of PVPPs are usually performed for the single location or municipality, like in the study of Potić et al. [14], but never for the whole territory of Serbia.

Based on the aforementioned, the purpose of this paper is to indicate the most desirable sites for development of ground-mounted PVPPs in Serbia by taking into consideration natural factors which are classified into three groups: climate, orography, and vegetation. The aim of this paper is to find out the optimal spatial pattern for PVPP and to calculate the electric energy generation for the top ranked locations in Serbia using AHP and GIS. In addition, the intra-annual variations in the efficiency of PVPP based on module temperature were explored.

The paper is organized as follows: description of the study area, applied methods and used data is presented in Section 2 (Methods and materials); the obtained results with supporting explanations and case studies for selected areas are included in the Section 3 (Results and discussion); and finally, conclusions are given in the Section 4.

2. Methods and materials

2.1. Study area

Serbia is located in the southeastern Europe on Balkan Peninsula with mathematical coordinates 41.43°N -46.11°N and 18.49°E- 23.00°E (see Figure 1). The parallel of 45°N passing through the northern part of the country, administrative province Vojvodina, which means that Serbia is a middle latitude country with prevalent moderate continental climate. The total country area is 88361 square kilometers with a population of 7186862 inhabitants (without autonomous province Kosovo and Metohija) in 2011 [15]. The northern part of the country has an altitude less than 200 m a.s.l. and presents a southern part of Pannonia Basin. Mountain area occupies a larger part of the territory, and spreading south of the rivers Danube and Sava with the highest altitudes more than 2000 m a.s.l. on the south, southeast and southwest. The main river valleys which drain this part of Serbia are Velika Morava, Zapadna Morava, and Južna Morava. Generally, lower terrains including areas along mentioned rivers are the most populated zones with the highest concentration of infrastructure capacities.

Fig. 1. Study area.

2.2. The MCE methods

Future distribution of PVPPs depends on many natural and socio-economic factors which can make electricity production at one location more reliable and cost-effective than on the others. In the planning practice, decisions about prospective sites for the development of

PVPPs are usually made intuitively or under different pressures by the decision makers. To create better and more functional spatial proposal, it is necessary to reduce the subjectivity during the assessment phase. That is the reason why planners often decide to use some well known methods of MCE, as such as Weighted Linear Sum (WLS), Simple Additive Weighting (SAW), Analytic Hierarchy Process (AHP), ELimination Et Choice Translating REality (ELECTRE), Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) etc.

2.2.1. The AHP method

The AHP is a multi-attribute method that has been used as one of the most popular and reliable methodology based on the reviewed literature. According to Malczewski [16], it is a third ranked method used in GIS multi-criteria decision analysis articles published between 1990 and 2004. Fields of application are various: environment and transportation [17], urban and regional planning [18], agriculture [19,20], tourism and recreation [21] etc. Numerous articles applied AHP to select an appropriate landfill site [22,23,24,25,26]. Mardani et al. [27] concluded that the AHP is the most popular technique in sustainable and renewable energy system problems. Nigim et al. [28] applied AHP and SIMUS (Sequential Interactive Model for Urban Sustainability) in order to rank project alternatives (solar photovoltaic, wind power, ground thermal or geothermal, micro-hydro, solar thermal energy) with respect to the criteria, and showed their practical usage for plans of developing renewable energy projects. The AHP was also used to select sites for wind farms [29,30,31], hydropower projects [32], concentrate solar power plants [33,34], and other renewable energy systems. Georgiou and Skarlatos [35] developed methodology based on AHP to quantify and evaluate land suitability for optimal site selection for sitting PVPP. In order to improve and limit evaluation only to the acceptable areas for PVPPs, the same authors excluded highly vegetated area, open water, and build-up land. In addition, nine constraint factors were used to create binary mask that reduced evaluated area. Xiao et al. [36] showed that AHP model successfully displays optimal sites for PVPPs in desert conditions. Many other authors [2, 3,4,6,14,37] also try to incorporate AHP in their framework in order to find the best location for PVPPs. Sánchez-Lozano et al. [4] concluded that AHP is the most appropriate solution mostly because it is widely accepted by the international scientific community as a powerful and flexible instrument for solving complex problems in the decision making process.

For the purposes of this study, AHP created by Saaty [38] was used. The essence of this method is in pairwise comparisons between elements in the form of the data matrix, wherein the number of rows and columns is defined by the number of elements that need to be measured up in accordance with the set objective.

In this case, the matrix of pairwise comparisons is created separately for criteria and factors. The intensity of importance for each pair in the matrix has been done using Saaty scale [39] of numerical values between 1-9, and their reciprocals (Table 1).

Table 1
The fundament scale [39].

Normalization of the data matrix was done by dividing each assigned numerical value with the sum of values in belonging column and then calculating the average for each row in the matrix. The obtained values represent weight coefficients (*w*) for each element in the matrix.

2.2.2. Consistency check

In order to check the consistency of the results, through the consistency ratio (*CR*), first it was calculated consistency index (*CI*) using the following equation:

$$CI = (\lambda_{max} - n)/(n - 1) \quad (1)$$

Where λ_{max} is the maximum eigenvalue of the comparison matrix and *n* is the number of elements in the comparison. The λ_{max} is calculated as the average of elements of the vector where every element is the ratio of the product of weight coefficients (*w*) and pairwise comparison matrix as numerator and vector of weight coefficients as denominator.

Finally, the consistency ratio (*CR*) is expressed as:

$$CR = CI/RI \quad (2)$$

Where *RI* is a random consistency index and its value depends on the size of the matrix ($n \times n$) and can be taken from the Table 2. If the *CR* value is less or equal than 0.10 then the matrix of pairwise comparisons had passed the consistency test.

Table 2
Values of the *RI* [40].

2.2.3. Criteria description

All relevant criteria that influence in the process of selecting most favorable sites for development of PVPPs are divided into two basic groups. The first group consists of the exception criteria that are used to reject those areas with more important purposes, or which are protected by special laws or due to its structure cannot be considered for the construction of PVPP [41]. It primarily refers to artificial surfaces, arable lands, and permanent crops, as well as, forest and wetlands. All these areas represent a resource for settlement, food production, the extraction of raw materials, the use of forests, outdoor activities, etc. Also, they have obstacles for smooth penetration of sun rays and construction of the PV systems. Excluded areas were extracted from Corine Land Cover (CLC) 2012 Version 18.5a database [42] and High Resolution Layer: Permanent Water Bodies (PWB) 2012 [43]. Specific types of excluded areas are shown in Table 3. Due to the increased risk of loss of biodiversity and fragmentation of habitats [44], as well as, visual burdens which might cause negative symbols on the human memory [45], it is recommended to install PVPP outside of protected natural areas. This is the reason why the protected areas were also excluded from evaluation. For that purpose, the Common Database on Designated Areas (CDDA), also known as Nationally Designated Areas [46] was used.

Table 3
Excluded and included areas in the evaluation.

After excluding some areas, the second criteria group was adapted to evaluate spatial suitability for this type of solar project. This is based on 3 criteria (climate, orography, and vegetation) and belonging 7 factors (global solar radiation, duration of sunshine, air temperature, relative humidity, slope, aspect, Normalized Difference Vegetation Index – NDVI). Table 4 presents all evaluation criteria and factors with corresponding marks. The entire process is implemented in the program ArcGIS Desktop 10.4. To enable overlap, the different cell values of input raster have been ranked and classified on the common grade scale (from 1 to 5, see Table 4). This is a way to normalize data about different factors (i.e. to compare data about climate and relief). Weighted coefficients for criteria (C_w) and factors (F_w), obtained as the result of the AHP were used as a multiplier in the spatial suitability index (*SSI*) showing the importance of each criteria and factor using the following equation:

$$SSI = \left[\mathrm{A}C_w \times \left((A_1F_w \times A_1G) + (A_2F_w \times A2G) + (A_3F_w \times A_3G) + (A_4F_w \times A_4G)\right)\right] + \left[BC_w \times \left((B_1F_w \times B_1G) + (B_2F_w \times B_2G)\right)\right] + [CC_w \times (C_1F_w \times C_1G)] \quad (3)$$

Where AC_w is the weighted coefficient for climate; A_1F_w is the weighted coefficient for global solar radiation; A_1G is the grade for certain class of global solar radiation; A_2F_w is the weighted coefficient for duration of sunshine; A_2G is the grade for certain class of duration of sunshine; A_3F_w is the weighted coefficient for air temperature; A_3G is the grade for certain class of air temperature; A_4F_w is the weighted coefficient for relative humidity; A_4G is the grade for certain class of relative humidity; BC_w is the weighted coefficient for orography; B_1F_w is the weighted coefficient for slope; B_1G is the grade for certain class of slope; B_2F_w is the weighted coefficient for the aspect; B_2G is the grade for certain class of aspect; CC_w is the weighted coefficient for vegetation; C_1F_w is the weighted coefficient for NDVI; C_1G is the grade for certain class of NDVI. The final model output is *SSI* map in form of raster data for the territory of Serbia.

Climate is considered to be one of the most important criteria in the evaluation of spatial suitability for the development of solar projects, and for that reason has the greatest weight coefficient in this study. Other criteria (orography and vegetation) were considered to have less importance because they can be adapted by human intervention on the terrain. Generally speaking, the territory of Serbia is characterized by moderate continental climate with more or less expressed local characteristics [47]. But these local climatic characteristics distinguish one place from the other in terms of the use of solar energy.

The PV systems use direct and diffuse solar radiation to produce electricity. That makes them more flexible in terms of site selecting, since they have a lower threshold of solar radiation that determines their efficiency compared with other solar systems. The solar radiation for the study area was derived from the European Digital Elevation Model (EU-DEM), Version 1.0 [48] by applying Area Solar Radiation tool in ArcGIS 10.4. Several input parameters were changed: sky size was set to 512, the time configuration was set to Multiple Days in a Year (the year 2016), the day and hour interval to 1, the zenith and azimuth divisions to 16, and Standard overcast sky was chosen for the diffuse model type. These settings are made according to the instructions from several available technical reports and studies with similar calculations in the same GIS environment [49,50,51,52,53,54]. The values for other parameters were retained to the default settings. The obtained raster for radiation has a resolution of 25 m and this is also spatial resolution of final model results. The global solar radiation values are presented in Table 4 using five equal classes.

Duration of sunshine is an important factor because solar energy is the intermittent source. If the sun does not shine, there will not be energy production or it will flow by the reduced amount. The same thing happens when the air is saturated with water vapor which acts as a barrier for absorbing and preventing unhindered penetration of sun rays. Also, the efficiency of PV system decreasing with increasing module temperature, and the global radiation, wind speed, and air temperature are significant in that process. The areas with lower average temperatures are more favorable in context enhancing of PV system performance. Data about annual average duration of sunshine, relative humidity, and air temperature for the period 1961-2010 were collected from 56 stations [55] in Serbia and interpolated by using Regression Kriging method in SAGA GIS software with EU-DEM [48], geographic latitude, and longitude as predictors. Regression Kriging presents a geostatistical method for interpolation various geospatial data where the spatial model consists of a deterministic and stochastic part [56]. Deterministic part of equation is based on the regression coefficients (model of generalized least squares) as an indicator of the spatial relation between predicted variable and predictors, while stochastic part consists of kriging weighed coefficients obtained from spatial relations of residuals. The exponential trend was used in variogram analysis. For the validity of interpolation model, the kriging variance was used. Obtained results, values of air temperature, relative humidity and duration of sunshine for the territory of Serbia, were reclassified into 5 equal classes, and the values and weighted coefficients were assigned according to Table 4.

Table 4
Criteria and factor weights with assigned grades used in the model.

Relief presents morphology of terrain and can be understood as a set of slopes of different categories of inclination [57]. From the engineering-geological point of view, the best sites for constructing PVPPs are those with flat and slightly sloping terrain oriented to the south [6]. Picking the right slope and aspect extracted from EU-DEM [48] could lead to higher energy production per area unit. In this regard, taking into consideration geographic position of the study area, the most favorable are southern slopes because they are sunny throughout the whole year and allowing denser arrangement of the panels, without the negative effects [58]. Therefore, the flat and southern oriented terrains gained higher grade than steeper and northern oriented terrains in this analysis (see Table 4).

Vegetation like the others physical forms in space prevent the development and smooth operation of PV systems and for that reason must be removed at the potential location. This can lead to the destruction of habitat and disturbance of fauna and flora, as well as, endangering of ecosystem services. To determine a density of green leaves on the study area, a layer was created by calculating the Normalized Difference Vegetation Index (NDVI) using satellite images recorded by the Landsat 8 OLI [59]. The NDVI is calculated as near-infrared radiation minus visible radiation divided by near-infrared radiation plus visible radiation. The NDVI values range from minus one (–1) to plus one (+1), so all values less and equal to 0 mean no vegetation, and close to +1 (0.8-0.9) indicate the high density of green leaves [60]. Higher value for NDVI means smaller grade and reversed (see Table 4).

3. Results and discussion

The *SSI* values indicate summarized influence of the selected criteria on the potential PVPPs locations in Serbia. The final map of *SSI* is presented in Figure 2. Obtained values are in the range from 1.77 (low suitability) to 4.25 (high suitability). Based on excluded criteria (rejection of areas for various purposes), 77.83% of the territory of Serbia were not subject of the evaluation process. The highest portion of these areas is located in the northern part of Serbia, in Vojvodina region, due to widespread of cultivated land and protected natural areas. Regardless, the most suitable land for the ground mounted PVPP has large distribution here. Also, the sites located along river valleys have the best scores; mainly along river Velika, Južna, and Zapadna Morava, in the entire zone from the south to the north, as well as along river Danube in the eastern part of Serbia i.e. Negotinska krajina and Dunavski ključ regions (for river valley positions see the Figure 1). Morphologically, Vojvodina represents a plain with altitude under 200 m a.s.l., and with other lowland valley areas, shows the most qualities for PVPPs construction. The other important factors are the solar radiation with the general decreasing trend from the south to the north of Serbia and sunshine duration with the generally increasing trend with reduction of vertical dissection of relief and for the sky open terrains. These factors are the most crucial for solar plant installation and energy yield; lower technical demands of construction in combination with appropriate solar energy input and a larger number of sunshine hours make some locations more favorable comparing to the others. Moreover, these areas overlap with the most populated zones and the highest energy consumption with existing infrastructure as a benefit for potential solar energy use. Obtained results have high spatial resolution and allow precise identification of the best sites for PVPPs construction in Serbia.

Fig. 2. The *SSI* values and existing ground-mounted PVPPs in Serbia.

In the next step, locations with the highest *SSI* values (>3.75) are explored in order to analyze their electric power generation potential (*GP*) applying the formula given by Gastli and Charabi [61]:

$$GP = SR \times CA \times AF \times \eta \tag{4}$$

Where *GP* represents electric power generation potential per year (GWh/year); *SR* is annual solar radiation per unit horizontal area (Wh/year/m^2); *CA* is the total area of suitable land (m^2); *AF* is area factor or percentage of suitable land that can be covered by PV panels; η is PV panel efficiency. Area factor of 0.70 (70%) was selected based on the maximum percentage of land that can be covered by PV panels with minimum shading effect [62]. According to International Energy Agency [63], the average efficiency of commercial silicon modules is 16% and this value was applied in the formula. The results are presented on municipality level in the format of thematic map (Figure 3). It is evident that even in the conditions of slightly smaller average annual solar radiation comparing to the southern municipalities, the most promising *GP* values has the northern part of Serbia, i.e. Vojvodina region and its part Banat, and especially the City of Zrenjanin, Municipality of Novi Bečej, and Municipality of Čoka with 37595 GWh/year in total. This is due to the large area covered by very suitable surfaces for the development of PV projects. Developing the PVPP only in these administrative units can supersede whole electric energy generation (37476 GWh during 2013) of the Public Enterprise "Electric Power Industry of Serbia" [64]. The next ranked administrative units with more than 4000 GWh/year electric energy generations are: Čoka, Kikinda, Sečanj, Sombor, Negotin, Zaječar, Vršac, Požarevac, Smederevo, and Kanjiža. Most of them are positioned in northern Serbia, while some are in the northeast and east. Concerning locations with highest *SSI* values, the *GP* was estimated to 249.2 TWh/year in total for the whole territory of Serbia, which is 6.6 times more than the best annual electric generation accomplished in the past 23 years of operation of EPS [64].

Fig. 3. The *GP* values for municipalities in Serbia. The existing PVPPs are marked.

Comparing the model results with the existing ground-mounted PVPPs in Serbia it showed that five of them are situated in excluded area, and two ("Matarova" and "Vrbovac") are in the suitable area (Figure 2). Solar park "Prima Energy" (996 kW) in Municipality of Beočin was partly built on agricultural land and for that reason, only its southern part covers the height *SSI* values, according to the model. The PVPP "Sajan" (Municipality of Kikinda) is developed on agricultural land which is not treated due to the poor quality of the soil. The PVPP "Solaris" (Municipality of Kladovo) is built on the former vineyard that eventually becomes unsuitable due to erosion process. The data about land use in this study are taken from CLC 2012, which is based on satellite images with 100 m resolution and minimum mapping unit of 25 ha. This is generalized for the purpose of this analysis and can exclude areas which in real life are suitable for PVPP. Beside the higher resolution of layer for exclusion, more accurate results would be obtained by integrating maps of agriculture land based on the category of capability.

3.1. Case study for eight locations

In order to show features of electric power generation per unit area, the locations with highest *SSI* scores are selected. For spatial planning purposes, the analysis is carried on parcel level. Using digital repository of Republic Geodetic Authority [65] belonging parcels to these locations were recognized and *GP* values are calculated. The results are presented in the Table 5. Calculated *GP* values are in the range from 1.26 GWh/year for a parcel in cadastral municipality Lukino Selo to 40.70 GWh/year for a parcel in cadastral municipality Taraš. With the isolation of the impact of parcel size, *GP* per unit of surface area is calculated. The obtained values are in the range from 129.55 kWh/m²/year to 135.21 kWh/m²/year for parcels in cadastral municipalities Dragovac and Korbevac, respectively. Variations in *GP* are results of solar radiation differences with the highest values for the most southern parcel. The other parcels are located in the north, in Vojvodina region. It should not be forgotten that *GP* refers to only radiation, and no other (climate) factors, and can be considered only conditionally.

Table 5
The *GP* values for eight parcels with the highest *SSI* scores.

The parcel with the highest *GP* per unit area value (in cadastral municipality Korbevac) is situated in the City of Vranje in the southern part of Serbia which is already recognized with good potential for solar energy use. According to a Spatial Plan of the City of Vranje [66], eighteen parcels with a total area of 4.3 square kilometers were recognized as potential locations for the solar power plant development. More of them are situated in the lower populated mountain area, mostly covered by forest, or on agricultural land in the valleys. The parcels in the Južna Morava valley have better natural conditions for PVPPs development, including the parcel in the cadastral municipality Korbevac which is recognized as a most suitable location according to the model results in this study. Other specified locations from Spatial Plan overlap with suitable or conditionally suitable classes of *SSI* model, are mostly covered with natural grasslands, but none of them belongs to the high suitability class. Based on the model results, the largest concentration of very suitable surfaces is located south of the urban settlement of Vranje, especially in village settlements situated in the valley area close to the administrative border with the Municipality of Bujanovac. The total area of high suitable surfaces in the City of Vranje covers 12.79 square kilometers and can generate around 1740.9 GWh of electric energy per year. Also, this is the zone of transport infrastructure (“Corridor X”) with recorded population growth. It has all necessary energy infrastructure (transmission lines and substations) and good transport links to support the development of new energy systems, making them cost efficient.

Another important issue devoted to operating ability of PVPP is intra-annual variability in electricity yield under different weather conditions. This is based on the fact that c-Si PV modules lose power with an increase of temperature above standard test conditions (25.0 °C) by rate 0.5-0.6%/°C [67]. Serbia is the middle latitude country with the prominent seasonal variation of climate parameters. In order to show these variations, the Faiman [68] model was used for calculating monthly module temperature (T_{mod}):

$$T_{mod} = T_{amb} + G/(U_0 + U_1 \times W_{mod}) \quad (5)$$

Where T_{amb} is ambient (air) temperature, G is incident irradiance, wherein two coefficients for crystal silicon modules U_0 = 26.9 and U_1 = 6.20 were taken as an average of the results published in the paper by Koehl et al. [69]. The wind speed data on the height of the modules (W_{mod}) are calculated by using Huld et al. [70] equation:

$$W_{mod} = (d_{mod}/d_{ane})^{0.2} \times W_{ane} \quad (6)$$

Where the W_{ane} is the wind speed at the height of anemometer, and d_{mod} and d_{ane} are the heights of the modules and the anemometer.

For calculating T_{mod}, the data from the nearest meteorological stations to selected parcels were analyzed. The first one, station Vranje (42.52°N, 21.92°E) is close to parcel Korbevac, and for other parcels which are situated in Vojvodina, T_{mod} is approximated using data from the station Zrenjanin (45.40°N, 20.38°E). Analyzed period is 2001-2010, and the source of data is RHMSS [55]. From the Figure 4 it can be seen that monthly values of T_{mod} have seasonal character, with exceeding critical threshold of 25.0 °C during the summer months for both stations. During average summer in Serbia, daily maximum temperatures can reach more than 40.0 °C and in these conditions, the efficiency of PV solar plant can be significantly affected. Moreover, average daily maximum temperatures for Vranje and Zrenjanin are 26.13 °C and 25.6 °C in June, 28.7 °C and 26.4 °C in July, and 29.8 °C and 27.3 °C in August (period 1981-2010). It is expected that the electricity consumption increases during the summer in particular, mainly due to home air conditioning [71,72]. This is very important for effective planning and solar energy use during the year. Furthermore, there is the wide range of factors which have to be considered before decisions on solar plant locations. Natural factors are basic and this research can help in this process.

Fig.4. The monthly values of T_{mod} for stations Vranje and Zrenjanin.

4. Conclusions

Using solar energy depends on a wide range of factors. Natural conditions in terms of incoming solar radiation, air temperature, sunshine duration, morphology of terrain, and vegetation cover, primarily determine the suitability of a certain area for the use of solar energy. This study represents the systematic evaluation of these factors for the territory of Serbia. Based on multi-criteria evaluation approach, the model with the high spatial resolution is developed and the most suitable sites for installation ground-mounted PVPPs are presented. The highest potential for PV systems is observed for the sites in the northern part of Serbia; the highest shares of these areas have the City of Zrenjanin, Municipality of Novi Bečej, and Municipality of Čoka. Their estimated potential is higher compared to the whole electric energy generation of the Public Enterprise EPS. The most suitable sites in Serbia have electric power generation potential per unit from 129.55 Wh/m²/year to 135.21 Wh/

m²/year. On the other side, there are additional factors which affect utilization of solar energy. Serbia is a middle latitude country and the seasonal aspect of the efficiency of PVPP should be considered. The overheating of the PV module surface affects its productivity during summer months. This requires a comprehensive and systematic approach for creating an adequate policy for the use of energy sources on the country level. The results of this study can be used to achieve this goal. Also, the future research will include socio-economic factors to get final insight in assessment of solar energy potential for the territory of Serbia. This is very useful for the establishment of national strategies and spatial plans for using renewable energy as well as environmental protection.

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Figure 1
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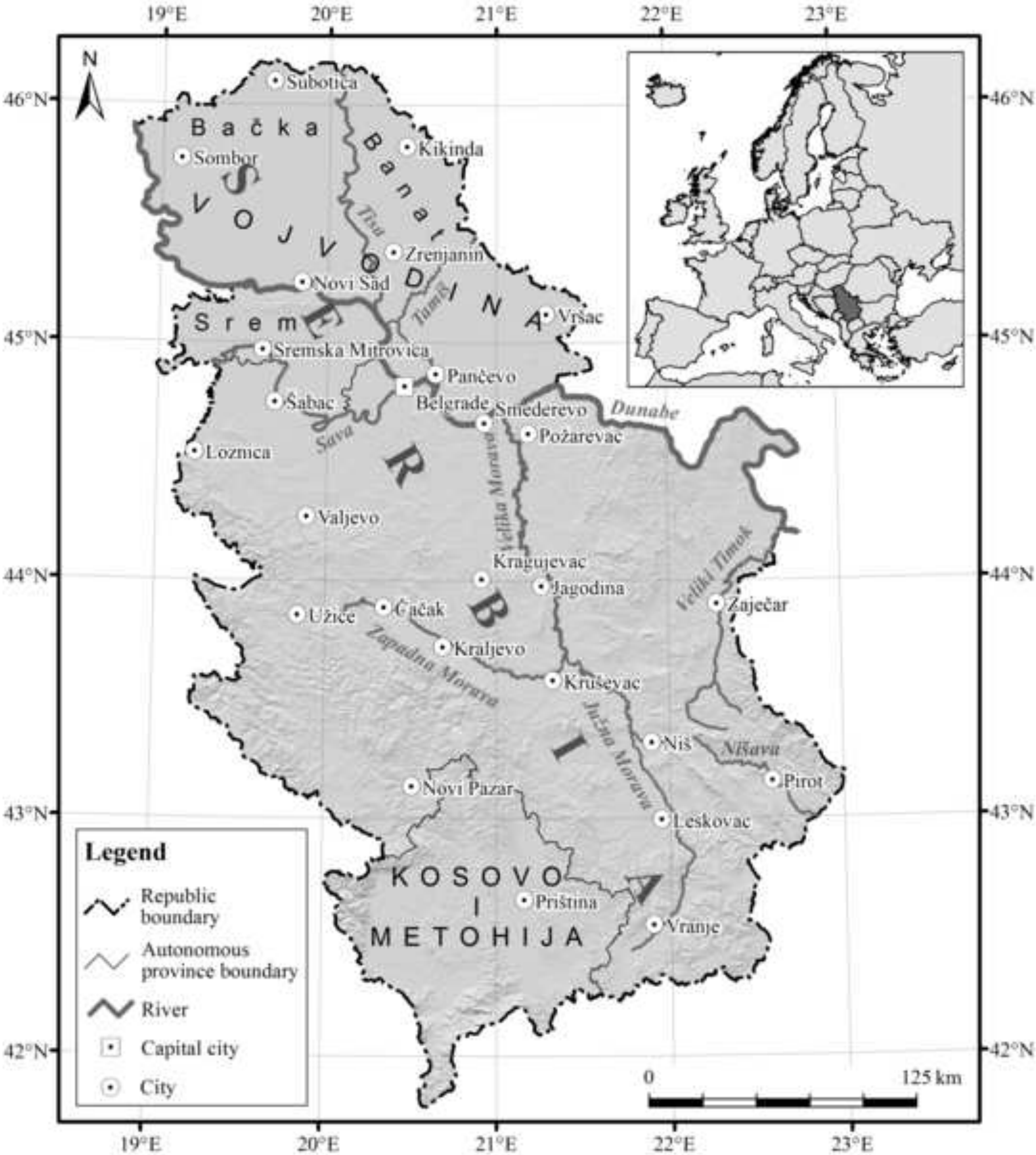

Figure 2
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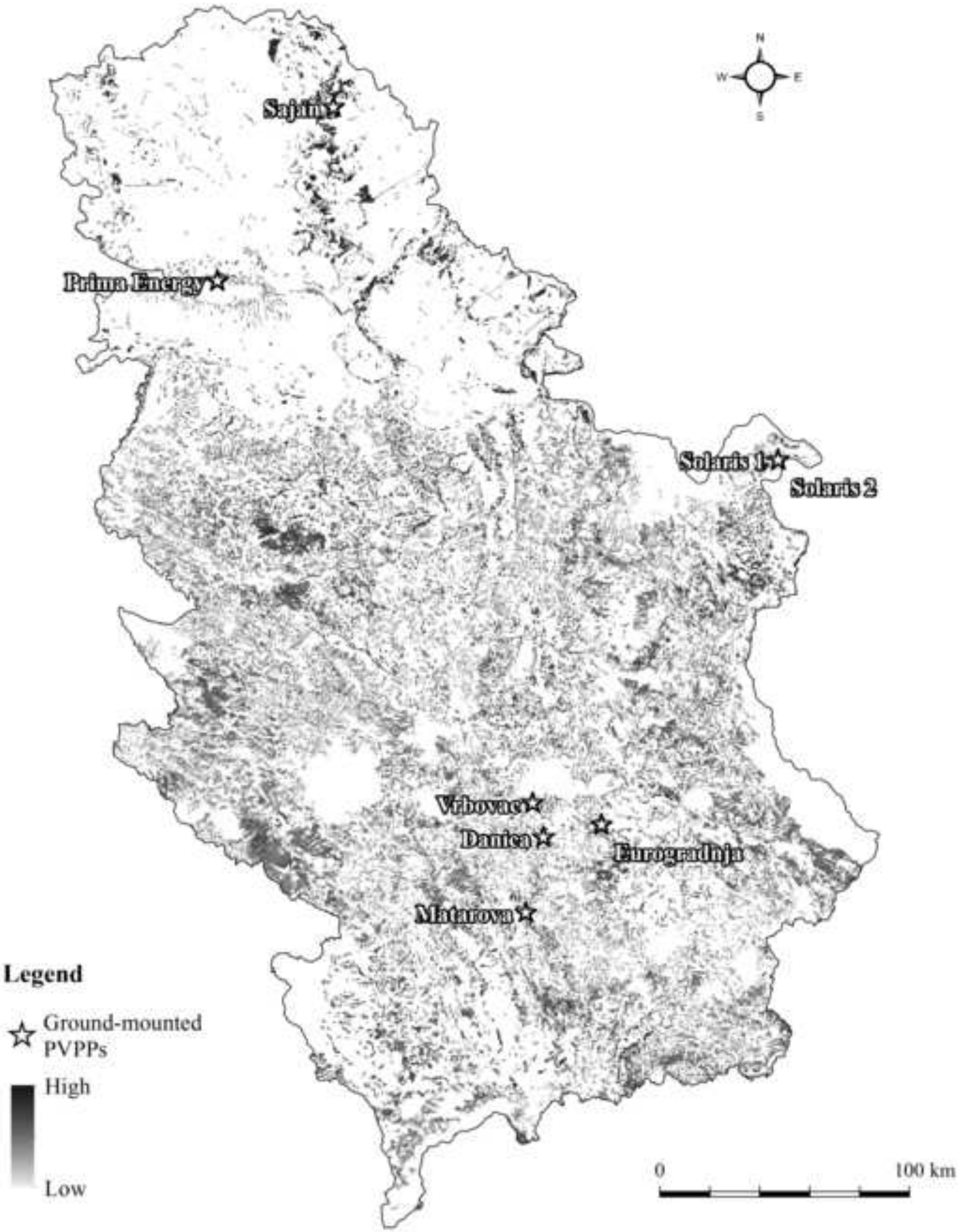

Figure 3

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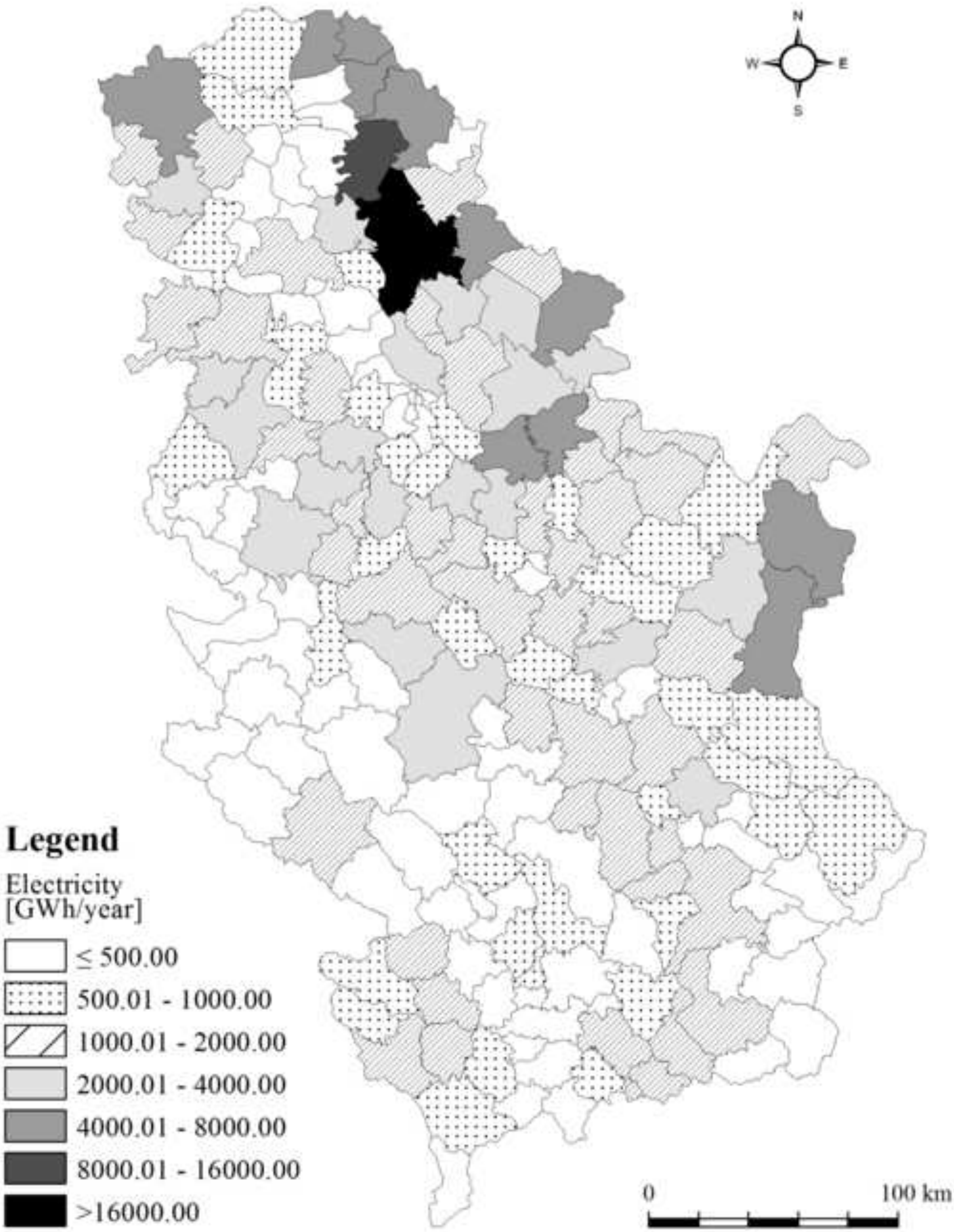

Figure 4

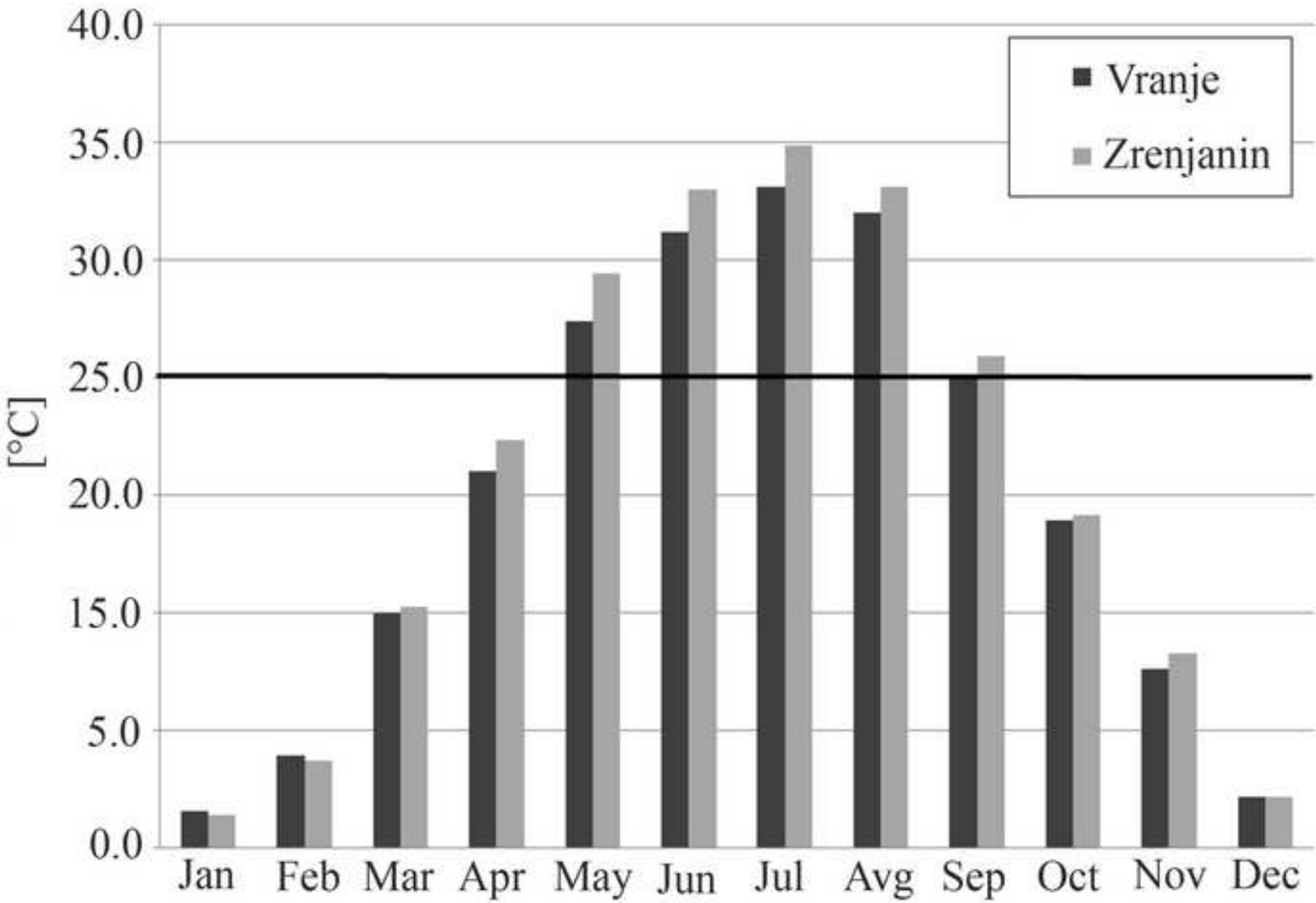
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Table 1

Table 1
The fundament scale [39].

Intensity of importance on an absolute scale	**Definition**	**Explanation**
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

Table 2

Table 2

Values of the *RI* [40].

Matrix size	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 3

Table 3
Excluded and included areas in the evaluation.

Excluded surface	**Included surface**
Continuous urban fabric; Discontinuous urban fabric; Industrial or commercial units; Road and rail networks and associated land; Port areas; Airports; Mineral extraction sites; Dump sites; Construction sites; Green urban areas; Sport and leisure facilities; Non-irrigated arable land; Rice fields; Vineyards; Fruit trees and berry plantations; Complex cultivation patterns; Broad-leaved forest; Coniferous forest; Mixed forest; Beaches, dunes, sands; Inland marshes; Peat bogs; Permanent water bodies; and Protected areas	Pastures; Land principally occupied by agriculture with significant areas of natural vegetation; Natural grasslands; Moors and heathland; Sclerophyllous vegetation; Transitional woodland-shrub; Bare rocks; Sparsely vegetated areas; and Burnt areas

Table 4

Table 4

Criteria and factor weights with assigned grades used in the model.

Criteria weight (C_w)	**Criteria**	**Factor weight (F_w)**	**Definition**	**Classes**	**Grades (G)**
0.648	Climate (A)	0.471	Global solar radiation (A_1) [$kWh/m^2/year$]	< 413.982	1
				413.982 – 746.758	2
				746.758 – 1079.535	3
				1079.535 – 1412.311	4
				> 1412.311	5
		0.284	Duration of sunshine (A_2) [h]	< 1958.903	1
				1958.903 – 1972.660	2
				1972.660 – 1986.417	3
				1986.417 – 2000.174	4
				> 2000.174	5
		0.171	Air temperature (A_3) [°C]	< 2.277	5
				2.277 – 4.716	4
				4.716 – 7.156	3
				7.156 – 9.956	2
				> 9.956	1
		0.074	Relative humidity (A_4) [%]	< 75.372	5
				75.372 – 76.854	4
				76.854 – 78.336	3
				78.336 – 79.817	2
				> 79.817	1
0.230	Orography (B)	0.667	Slope (B_1) [°]	< 2	5
				2 – 5	4
				5 – 12	3
				12 – 32	2
				> 32	1
		0.333	Aspect (B_2)	Horizontal and South	5
				Southeast and Southeast	4
				East and West	3
				Northeast and Northwest	2
				North	1
0.122	Vegetation (C)	1.000	NDVI (C_1)	< 0	5
				0 – 0.2	4
				0.2 – 0.4	3
				0.4 – 0.6	2
				> 0.6	1

Table 5

Table 5
The *GP* values for eight parcels with the highest *SSI* scores.

Cadastral municipality	Solar radiation [kWh/m^2/year]	Surface [m^2]	*GP* [GWh/year]	*GP* per unit area [kWh/m^2/year]
Ečka	1161.06	11191	1.45	130.04
Lukino Selo	1157.12	9744	1.26	129.60
Lukino Selo	1157.08	59340	7.69	129.59
Taraš	1157.10	314084	40.70	129.59
Banatska Dubica	1164.92	208378	27.19	130.47
Korbevac	1207.20	89722	12.13	135.21
Banatski Karlovci	1158.84	38287	4.97	129.79
Dragovac	1156.70	89639	11.61	129.55