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GEOSPATIAL EVALUATION OF BELGRADE FOR THE PURPOSES OF DETERMINATION OF SUITABLE LOCATIONS FOR THE CONSTRUCTION OF PV PLANTS

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ABSTRACT

The aim of this paper is to identify the most suitable locations for the construction of Solar Photovoltaic Plants (PVP) on the territory of the City of Belgrade (Republic of Serbia). The city is rich in natural resources and abundant in energy potential. The climatic and spatial characteristics favor the use of solar energy: the average annual solar radiation in Belgrade is 1446.8 kWh/m^2/year, and the sunshine duration is around 2200 h/year.

The analysis covered the area of 3240.7 km^2 (administrative area of Belgrade). Geospatial evaluation was based on three basic criteria: aspect, slope and land use. The Method of elimination in combination with modern methods in geospatial research (GIS) was applied. Based on the mentioned geospatial factors, thematic maps were made and later, their overlapping resulted in obtaining a synthesis Map of the suitability of the terrain for the construction of the PV plants. Of the total considered area, 13.68% were evaluated as suitable for the given purpose.

Key words: *solar energy, PV plants, Belgrade, GIS*

INTRODUCTION

Projections from numerous researchers and international agencies dealing with climate change, energy efficiency, etc. show that non-renewable energy sources will be dominant by 2030 when RES will take over the first place [1]. Solar energy is suitable for use because it does not pollute the environment, and is present in unlimited quantities [2]. Solar energy is manifested in the form of light and heat. The principle of solar energy conversion is based on the use of thermal solar collectors and photovoltaic cells.

The expansion of photovoltaic cells has been made possible by significant technological advances over the last decade. Solar photovoltaic (PV) systems, which directly convert sunlight into electricity, are particularly suited to electrifying both urban and rural areas [3]. The power produced by the photovoltaic (PV) system depends on a wide range of factors, among which are those that can be altered in the planning, installation and operation phase to minimize losses [4].

According to Djurdjević [5] Serbia has some areas with favorable, but mostly good conditions for solar PV electricity production. The estimated technically usable potential of renewable energy in Serbia ranges between 5.6 Mtoe and 6 Mtoe, while for solar energy this value ranges between 0.2 Mtoe and 0.6 Mtoe (million tons of oil equivalent). The average number of sunny hours in the territory of Serbia ranges between 1500 and 2200 hours per year, and the average number of sunny days is 270. The average solar radiation in Serbia is 30% higher than in Europe [6].

This is why solar energy and its potentials in Serbia have been the subject of numerous studies over the last decade. Čorba and others in 2017 [7] presented the possibilities of irrigation of different agricultural crops in the territory of Serbia, using solar irrigation systems. In studied 2006 the link between solar energy and sustainable development [8].

Analyzed the energy potential of the Sun in Serbia and the application of solar energy in various fields of agriculture [9]. Presented practical examples of the use of solar potential in the example of the photovoltaic power plant "FTS Novi Sad" [10]. In her doctoral dissertation [11] studied the energy efficiency of solar power plants in the Republic of Serbia and the Republika Srpska. Doljak et al. in 2018 estimated the photovoltaic power generation potential in Serbia based on irradiance, air temperature, and wind speed data [4].

STUDY AREA

Belgrade is a city of international importance with the highest level of urbanization in the Republic of Serbia. It is the administrative center of Serbia, acting as the center of economy, tourism, transport, education and culture [12]. Belgrade, as the most economically developed region in state, is in a position to introduce greater use of solar energy faster than other local governments. The city of Belgrade is located in Southeastern Europe, on the Balkan Peninsula. It lies at the mouth of the Sava River into the Danube, between their alluvial planes, near the Mountain Avala (511m a.s.l.). The average elevation of the city is 132 m. The study area is located in a continental climate region, so the largest amount of solar energy is received during the summer season, especially during July and August, and the lowest during winter (in January and December).

According to the available data, the territory of the City belongs to the areas relatively rich in solar energy. The annual average of daily Global Horizontal Irradiance (GHI) for the surface with a slope of 30° and south orientation is between 3.76 kWh/m^2 and 3.86 kWh/m^2 for Belgrade. The value of average annual solar radiation is 1446.8 kWh/m^2/year [13].

MATERIAL AND METHOD

The subject of this paper is the territory of the City of Belgrade and the potential of using solar energy in a given area. The aim of the research is to identify the most favorable areas for the construction of solar photovoltaic plants. The analysis covered the area of 3240.7 km^2, which coincides with the administrative territory of Belgrade, that is the territory of 17 city municipalities (Map 4). The evaluation was performed by applying the Method of elimination in combination with modern methods in geospatial research (GIS).

The three main criteria on which the research was based were: aspect, slope and land use. Based on the mentioned geospatial factors, thematic maps were made, and later their overlapping resulted in obtaining a synthesis Map of the suitability of the terrain for the construction of the PV plants. For the needs of evaluation, geospatial analysis and cartographic presentation of the results, GIS software (QGIS 3.8) was used.

The shape and characteristics of the relief have a strong influence on the properties of a particular area and thus determine how it is used. Aspect and slope are the primary morphometric parameters of the relief [14]. Aspect indirectly influences the natural conditions and the intensity of different processes

in the environment. The exposure and duration of the sun's glow, the temperature sum, and their amplitude depend on the aspect [14,15]. The slopes with the south (S), southwest (SW) and southeast (SE) aspect are most suitable for the construction of PV plants, together with flat (unexposed) surfaces which are considered also as favourable [16]. The most widespread is the SW aspect, which covers 13.58% of the total area. Suitably exposed locations for the installation of PV plants cover 1167.27 km^2, or 36.02% of the total Belgrade area (Table 1, Map 1).

Table 1. The aspect of the relief of the City of Belgrade

Aspect	Surface (km^2)	Share in the total area of the City (%)
N	377.07	11.64
NE	405.35	12.51
E	410.73	12.67
SE	355.25	10.96
S	371.85	11.47
SW	440.17	13.58
W	439.89	13.57
NW	381.59	11.77
Flat	58.81	1.81

The slope has a great influence on the reception of the sun's rays, the oscillations of the surface temperature and the air. In addition to influencing the incident angle of solar radiation, the slope is also significant for construction conditions. According to [16] locations with a slope of up to 10° are favourable for the installation of PV plants. Suitable areas according to this criterion occupy 93.79% of the total territory (Table 2, Map 2).

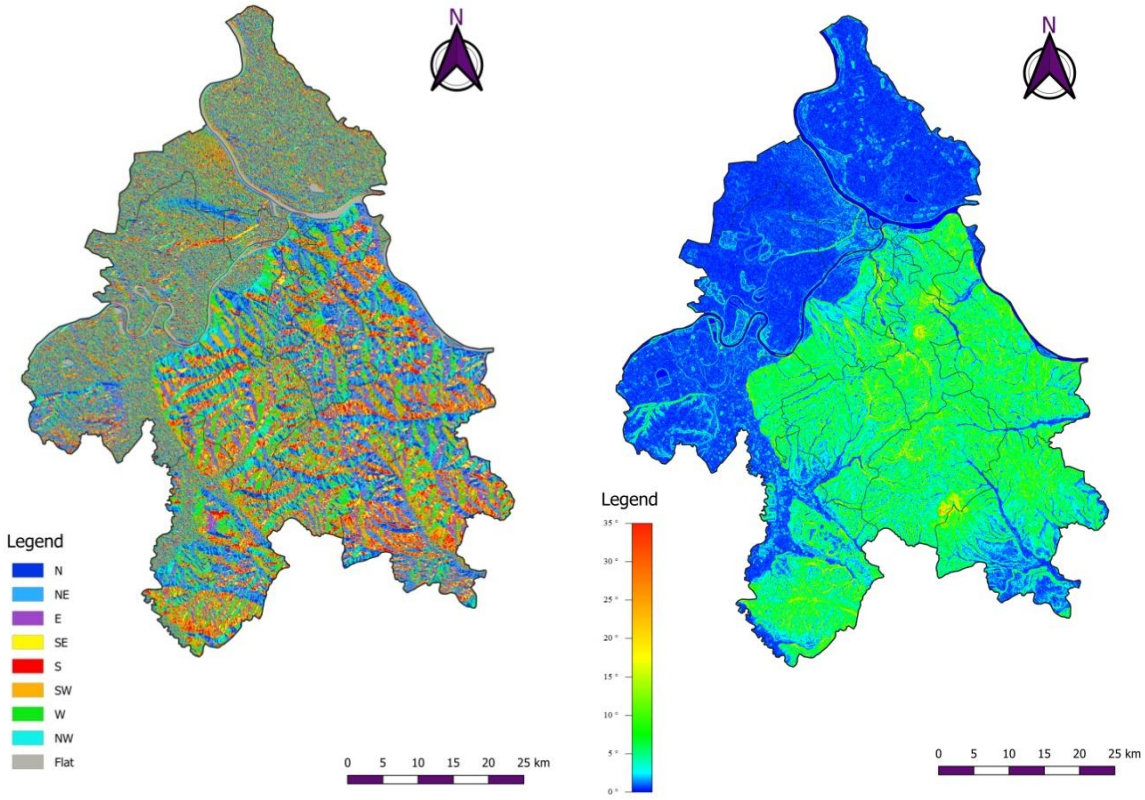
Table 2. The values of the slope angles of the territory of the City of Belgrade

Slope (°)	Surface (km^2)	Share in the total area of the City (%)
0 - 5	2224.14	68.63
5 - 10	815.32	25.16
10 - 15	174.39	5.38
15 - 20	22.79	0.70
20 - 25	3.44	0.11
25 - 30	0.53	0.02
30 - 35	0.1	0.003

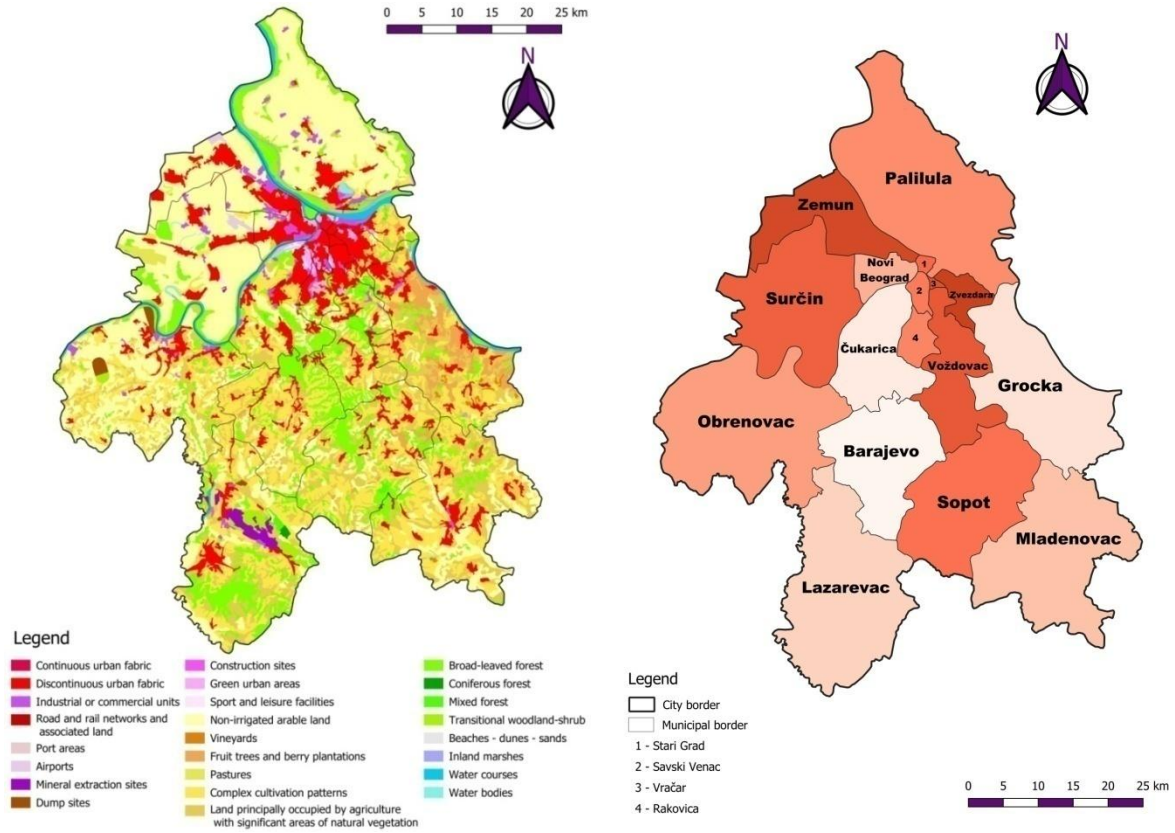
Last but not least investigated factor is land use. In urban areas such as Belgrade, which are characterized by very dense construction and high population density (Vračar 19161 inhabitants/km^2), where a large number of different economic and social activities occur, an analysis of this factor is essential, in order to determine sites that have sufficient free space to build a larger system such as solar power plant. In order to obtain data on land use, a digital database on the status and changes of the land cover and the way of land use throughout Europe CORINE Land Cover (CLC 2018) [17] was used.

Pastures (0.97% of the total area), land principally occupied by agriculture with significant areas of natural vegetation (15.9%), complex cultivation patterns (19.67%) and transitional woodland-shrub (3.3%) are the most suitable areas for the given purposes. Such surfaces are eligible because there are no larger structures and they are generally easily accessible.

Undoubtedly, when selecting locations, it is advisable to avoid high quality, fertile land. Suitable areas in terms of land use cover 1291.03 km^2 or 39.84% of the total surface and they are predominantly represented in the part of the city south of the Sava and Danube river (Map 3).



Map 1 and 2. The aspect and slope of the terrain of Belgrade



Map 3 and 4. Land use on the territory of Belgrade/Study area- Belgrade's urban municipalities

RESULTS

In order to adequately define the solutions related to the construction of facilities or systems that use or produce energy from renewable sources, it is necessary to identify and graphically present the findings in the planning documents and different studies [18]. By collecting the necessary data, overlapping thematic maps and conducting geospatial analyses, the suitability of the considered area for the needs of the construction of PV plants was evaluated. The findings obtained in this paper showed that 13.68% (443.39 km^2) of Belgrade region is rated as favorable for the given purposes.

Suitable locations have not been recorded in the city municipalities of Vračar, Stari Grad and Savski Venac. Those are the most densely populated and constructed parts of Belgrade. In such central city areas, where there is no possibility for the construction of large installations, it is possible to use roof surfaces of buildings for the exploitation of solar energy by the use of solar panels. Likewise, Nasov et al. proposed the use of facade solar thermal collectors in construction. They are relatively easy to install and can be applied to all types of buildings [19]. In those locations where there are appropriate conditions, it is desirable to place solar panels, especially on objects of public importance, where there are a large number of users such as preschool and school institutions, hospitals, health centers, scientific institutions, courts, etc. Furthermore, apart from public buildings, it is necessary to include in the solar energy system the housing facilities, commercial and business buildings, etc. In this way, in addition to saving resources (the fossil fuels currently most used to meet Belgrade's energy needs), there are also long-term material benefits for consumers, due to reduced electricity bills generated from conventional sources.

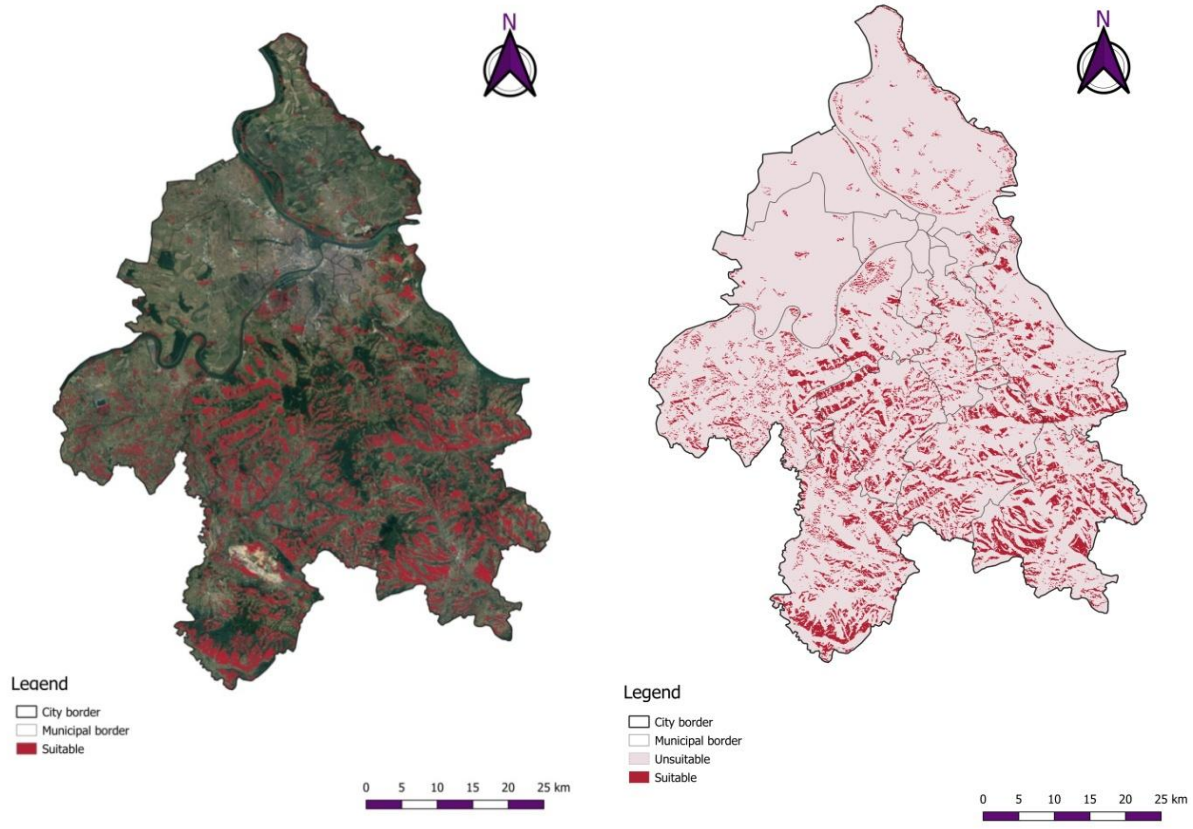
The municipalities of Zemun, Surčin and New Belgrade have the lowest percent of suitable areas. New Belgrade, which in the past was distinguished by its open space, was quickly affected by intensive construction. Although morphological conditions are almost ideal, suitable locations cover only 1.67% (0.68km^2). This is a great example of how land use is an important factor. This urban municipality is slowly becoming the new most important business zone of Belgrade. New Belgrade's various traffic connections, easy access to the highway, wide roads – boulevards, proximity to Nikola Tesla International Airport and business growth contributed to this [20]. In this group the least suitable is in Zemun with just 1.41 km^2 (0.95%).

Municipalities located south of the Sava and Danube rivers were rated as generally favourable. These areas are distinguished by their convenient morphological characteristics of the relief and the present land uses. Here terrain gradually descends from the south towards the north in the form of vast planes. The most common is flat to slightly sloping terrain with a slope of up to 5° (68.63% or 2224.14 km^2). Medium and very steep terrain (20°-30°) covers 0.12% of the surface, while extremely steep terrain (>30°) covers only 0.003%. A certain share of suitable locations was recorded in the these territory such as Grocka, Obrenovac, and Čukarica (between 13% and 15% of the total territory). Obrenovac is location of the first solar photovoltaic power plant in Serbia that uses special integrated photovoltaic cells. It was installed in 2012 in settlement of Stubline [21].

The municipalities of Mladenovac, Barajevo, Lazarevac and Sopot belong to the group with the highest share of suitable locations (over 20%) (Map 5). In the territories of these municipalities, slopes of up to 10° are predominantly represented as well as south (S), southeast (SE) and southwest (SW) aspect. Land use is also advantageous, given that significant areas are represented by agricultural land with natural vegetation and transitional woodland-shrub. Mladenovac stands out in particular, which is in the first place with 80.68 km^2 or 23.49% of the total city area (Table 3). The mentioned municipalities together participate with 87.7% (266.71 km^2) which practically means that they have the greatest potential for the construction of such facilities. It is important to emphasize that this is a less economically developed part of Belgrade, located in the suburban area as well as less equipped with infrastructure compared to the central urban zones. Therefore, the use of solar energy in the future may be the backbone of their development.

Table 3. Suitable surfaces for the construction of PV plants in Belgrade's urban municipalities

Municipality/City	Surface of the municipality (km^2)	Surface of the suitable areas (km^2)	Share in the total area of the City (%)
Barajevo	215.3	47.5	22.06
Čukarica	157.26	20.88	13.28
Grocka	294.61	46.96	15.94
Lazarevac	382.74	81.67	21.34
Mladenovac	343.52	80.68	23.49
Novi Beograd	40.67	0.68	1.67
Obrenovac	411.15	56.14	13.65
Palilula	447.58	24.38	5.45
Rakovica	31.63	2.02	6.39
Savski Venac	14.57	0	0
Sopot	273.21	56.86	20.81
Stari Grad	5.34	0	0
Surčin	289.5	4.81	1.66
Voždovac	147.45	16.46	11.16
Vračar	2.49	0	0
Zemun	148.94	1.41	0.95
Zvezdara	34.74	2.94	8.46
BELGRADE	3240.7	443.39	13.68



Map 5. Locations suitable for the construction of PV plants in Belgrade

CONCLUSION

The main goal of this paper was to determine the most favorable locations for the construction of PV plants in the City of Belgrade. Belgrade was chosen as the subject area because it posses the technical, financial and institutional capacities, as well as the natural conditions necessary for the implementation of major projects. The local climate as a factor plays an important role in the planning of the use of RES, especially when it comes to solar energy or e.g. wind energy. The territory of Belgrade is one of the areas in Serbia generally rich in solar energy. The value of average annual solar radiation in Belgrade is 1446.8 kWh/m^2/year.

Regarding morphological characteristics (aspect and slope) and land use, the results of the research confirmed the starting assumptions. Suitably exposed locations for the installation of PV plants cover 36.02% and favorable areas according to the slope criterion occupy 93.79% of the total territory. The third evaluation criterion was land use. All four basic categories of land use were taken into account - agricultural, water, forest, and construction land, with their subcategories. The results showed that suitable land use areas cover 39.84% of the total territory.

Finally, 13.68% of Belgrade's region belongs to the category of suitable construction zones. The municipality of Mladenovac stands out in terms of obtained values - 23.49% of the total city area (nearly ¼). The central urban area was singled out as the most unfavorable zone (Vračar, Savski Venac i Stari Grad).

The overall conclusion is that the City of Belgrade, as well as a significant part of the Republic of Serbia, possesses the climatic and morphological conditions that are necessary for the construction of large systems intended for the conversion of solar energy. Further research regarding the use of solar potential in Serbia should be conducted on the basis of examples of more developed countries: to develop an adequate and up-to-date information system and to apply GIS technologies in determining the potentials and locations for the use of this type of renewable energy.

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