

PRIRODNI I ENERGETSKI POTENCIJALI SOLARNE ENERGIJE NA TERITORIJI OPŠTINE NEGOTIN

NATURAL AND ENERGY POTENTIALS OF SOLAR ENERGY WITHIN THE NEGOTIN MUNICIPALITY

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U savremenom svetu pravilna primena koncepta održivog razvoja ne bi bila moguća bez upotrebe obnovljivih izvora energije. Rad prikazuje identifikaciju pogodnih lokacija za izgradnju solarnih elektrana u opštini Negotin, koje bi u značajnoj meri redukovale korišćenje fosilnih goriva na toj teritoriji. Za pravilnu analizu stanja terena, korišćeni su geografski informacioni sistemi. Upotrebom geografskih informacionih sistema (GIS) izvršene su analize prirodnih uslova: nagiba terena, ekspozicije, načina korišćenja zemljišta, prirodnih hazarda i zaštićenih prirodnih područja. Kabinetskim radom, metodom valorizacije i eliminacije putem softverskih GIS paketa izvršena je analiza i interpretacija prirodnih karakteristika na svim kartama pojedinačno. Obradom svih karata, dobija se finalna, sintezna karta pogodnosti primene solarne energije na teritoriji opštine Negotin, koja je odabrana na osnovu veoma povoljnih klimatskih uslova. Na osnovu sintezne karte i dobijene površine pogodnih lokacija za primenu solarne energije, izvršena je analiza i proračuni potencijalne instalisane snage solarnih elektrana u ovoj opštini kako bi se dobio adekvatan prikaz količine električne energije koja se može proizvesti iz fotonaponskih sistema solarnih panela.

Ključne reči: *Solarna energija; pogodne lokacije; GIS; energetika; Negotin*

Nowadays, the proper implementation of sustainable development would not be possible without the usage of renewable energy resources. The main aim of this paper is oriented towards identification of proper location for the construction of solar power plants within the Negotin municipality, which could significantly reduce the usage of fossil fuels within this territory. Geographic information system (GIS) was conducted for detail analysis of the stated terrain, including the analysis regarding the natural conditions, such as the terrain inclination and its exposure, the manners of the land usage, natural hazards, as well as the analysis of protected areas. Methods of valorization and elimination of different locations throughout the GIS software were used for analysis of natural characteristics throughout the different maps, while processing the all maps together resulted in one final synthetic map. This map pointed to the potentials for using the solar energy on the territory of the Negotin municipality, based on the analysis of the most favorable climatic conditions. Synthesis map also pointed to the area with suitable locations for application of the solar energy. Finally, the analysis and calculations of the general potentials of installed power of solar plants within this municipality were performed in order to obtain the adequate representation of the amount of the electricity that could be produced from photovoltaic solar panel systems.

Key words: *Solar energy; suitable locations; GIS, energetic; Negotin*

1 Introduction

Ever since dawn the industrial revolution it has been clear that the world cannot rely solely on fossil fuel exploitation to meet its energy needs. Due to the limited amount of oil, coal and gas, as well as their negative impact on the environment, it was necessary to find an alternative that would generate electrical and thermal energy without major consequences for the environmental quality and human health. This kind of "clean" energy is now obtained from renewable energy sources. The energy of the Sun, water, wind and biomass enables the supply of energy to the population with minimum environmental impacts and zero CO₂ emissions, which significantly contributes to the implementation of the sustainable development concept and climate change intensity reduction. "Clean" energies are those types of energy whose use or conversion to mechanical or electrical energy does not in any way

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disturb the balance in nature or pollute the nature and its flows, with reduced CO₂ emission in the energy production process [1]. Development of renewable energy sources and their use, as well as reduced energy consumption (energy efficiency), implies the reduction of greenhouse gas emissions [2]. Today, RESs are used in various parts of the world, although they are still not used to a sufficient extent.

The Republic of Serbia boasts of the potentials of Solar energy, hydropower, geothermal energy, wind and biomass energy. For the purposes of this paper, natural and energy potentials in the municipality of Negotin, located in the eastern part of the country, have been explored. Solar energy is a type of RES with the greatest potential in the world. Solar power plants are extremely important energy facilities yielding "pure" electrical energy, which today is the goal of many world organizations.

Photovoltaic energy conversion is the present and future of solar energy in the world. The reasons why the municipality of Negotin was chosen for research were favourable climatic and orographic conditions. On average, Serbia has more sunshine hours than most European countries [3]. Geographic information systems were used to obtain relevant data on the solar energy potential in this municipality. Using the available database, satellite images and their processing in geographic software systems, relevant data are obtained which, in combination with field research, can be extremely precise [4]. By the method of elimination and valorisation, 5 factors are distinguished for the Municipality of Negotin: terrain aspect (solar exposure), land slope, land use, protected natural assets and natural hazard (landslides). On the basis of the obtained results, the calculations of the potential installed power of solar power plants were made.

2 Materials and methods

GIS tools were used for the purpose of determining suitable locations for solar power plants. The method was cabinet work providing easily accessible data that could be largely used for the analysis of natural conditions and obtaining analytical and synthetic maps. In the aforementioned software packages, 5 analytical maps were processed based on which the final, synthetic map of suitability was formed.

The terrain aspect map (S_1) shows the solar exposure of the terrain, i.e. orientation of the terrain in relation to the Sun. Since Serbia is located on the northern hemisphere, the exposition in which the solar intensity is highest is southern, so the southern cardinal direction is most suitable for the construction of solar power plants in our country.

The terrain slope map (S_2) is a very important factor for solar energy potential. The most suitable terrains are those with an exceptionally gentle slope, for easier accessibility during construction of power plants and reduced risk of possible accidents whose chances increase with terrain slope.

The Corine Land Cover database [5], from which the classes of land use were taken, was used for the purposes of obtaining the land use map (S_3). Depending on the land use, valorisation was done based on the suitability for the construction of power plants.

Due to their exceptional ecological importance, protected natural assets in the Republic of Serbia do not allow greater anthropogenic activity, therefore protected areas must also be considered with the aim of avoiding the construction of solar power plants.

An extremely important natural and anthropogenic condition are geomorphologic disasters that may be present to a greater or lesser extent, so the sixth analytical map that was processed is a map of natural hazards, i.e. a map of existing landslides that shows areas that are unsuitable for the application of solar energy.

Based on the processing and analysis of 5 maps, a final, synthetic map is obtained to represent a combination of values of all individual maps. The synthetic map formation was determined by the following procedure:

$$S_k = \frac{\sum_{i=1}^3 S_i}{n} = \frac{S_1+S_2+S_3}{3}, \text{ where}$$

S_k - Synthetic map S_i - individual maps n - number of maps with the elimination of inconvenient locations obtained from the protected areas and landslides maps.

The analysis of the synthetic map and identification of areas that are most suitable for the construction in power plants, based on the processed calculations, generate the potential of the total in-

stalled power of solar power plants. Factors that have been processed include surface area of the most suitable location, surface area of solar panels, power of solar panels, and potential investment.

3 Results and discussion

According to the RHMSS data [6], the municipality of Negotin, covering a surface area of slightly less than 1,090 km², is characterized by slightly more favourable climatic conditions compared to other parts of Serbia.

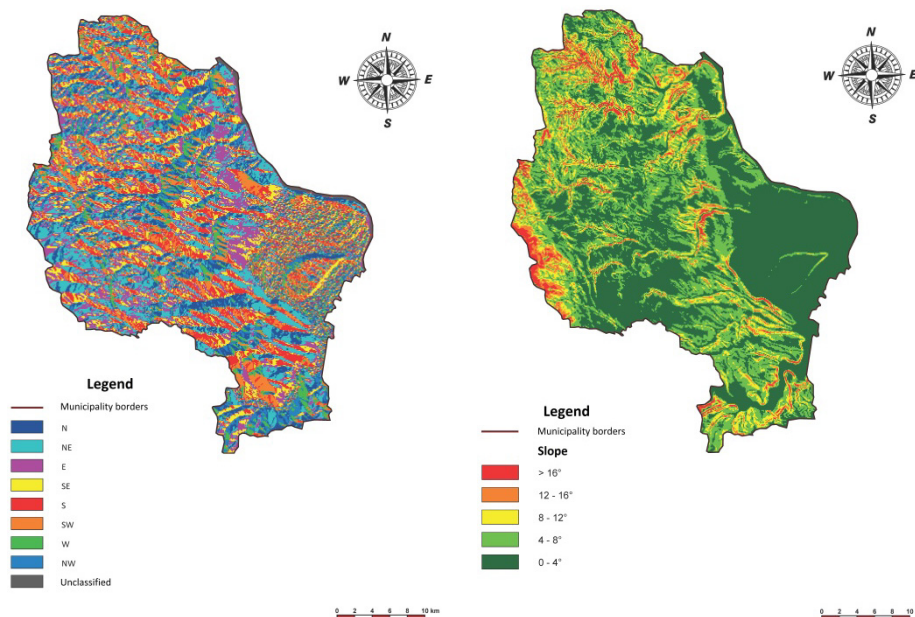
Table 1: Insolation level in the territory of Serbia

| Number of sunshine hours in the 2012-2016 period | | | | | | | |
|--|--------|--------|--------|--------|--------|-----------|---------|
| | 2012 | 2013 | 2014 | 2015 | 2016 | Total (Σ) | Average |
| Negotin | 2582,8 | 2220,1 | 1987,8 | 2353 | 2195,5 | 11249,2 | 2249,8h |
| Sombor | 2505,1 | 2103,2 | 2005,8 | 2160,8 | 2056,6 | 10831,5 | 2166,3h |
| Niš | 2153,1 | 1937,1 | 1871,7 | 2071,6 | 1911,7 | 9945,2 | 1989h |
| Loznica | 2319,8 | 2068,1 | 1842,9 | 2125,4 | 1994,9 | 10351,1 | 2070,2h |
| Kragujevac | 2222,6 | 2009,1 | 1800,8 | 2085 | 1908,6 | 10026,1 | 2005,2h |

From Table 1 it can be seen that in the last 5 years Negotin had significantly more hours of sunshine compared to other given cities that are located in different parts of the country, which indicates that the solar panels operation would be most strong in the municipality of Negotin, with the annual average insolation of 2249.8h.

Table 2: Cloud cover in Serbia

| Number of days when cloud cover in < 2 / > 8 in the 2012-2016 period | | | | | | | |
|--|--------|--------|--------|--------|--------|-----------|---------|
| | 2012 | 2013 | 2014 | 2015 | 2016 | Total (Σ) | Average |
| Negotin | 133/87 | 110/99 | 68/135 | 111/77 | 97/78 | 519/476 | 104/95 |
| Sombor | 94/76 | 65/108 | 72/103 | 83/108 | 56/92 | 380/487 | 76/97 |
| Niš | 119/92 | 96/93 | 59/110 | 101/96 | 71/115 | 446/506 | 89/101 |
| Loznica | 94/107 | 68/116 | 46/127 | 81/101 | 58/102 | 347/553 | 69/111 |
| Kragujevac | 100/90 | 69/92 | 52/99 | 83/98 | 55/114 | 359/493 | 72/99 |



Figures 1 and 2: Terrain aspect and slope maps

Table 2 analyzes a very important climatic element, cloudiness. As cloudiness is shown in oktas, the value < 2 indicates very clear weather, while the value > 8 shows extreme cloudiness. For photovoltaic cells and their work, it is extremely important whether the solar radiation will come by direct or diffuse path. In relation to other given cities, the municipality of Negotin has the highest number of clear and the lowest number of cloudy days, so it can be concluded that direct solar radiation (providing greater power to PV cells than the diffuse) is most intense here.

The results of analytical maps and the final, synthetic map, were obtained by processing maps in GIS. The greater presence of the north and south cardinal direction can be seen on the terrain aspect map. The southern aspect was selected with the highest rating in the evaluation, where the intensity of solar radiation is most pronounced.

The terrain slope angles map shows the degree of land inclination. It can be noticed on the map that the terrain angle in the eastern part of the municipality is most suitable.

The land use is an extremely important factor in valorizing natural conditions. A large part of unirrigated areas is noticed in the eastern part of the municipality of Negotin, which are taken as areas with the best rating. Deciduous forests, as well as woody and bushy vegetation, are also present to a great extent.

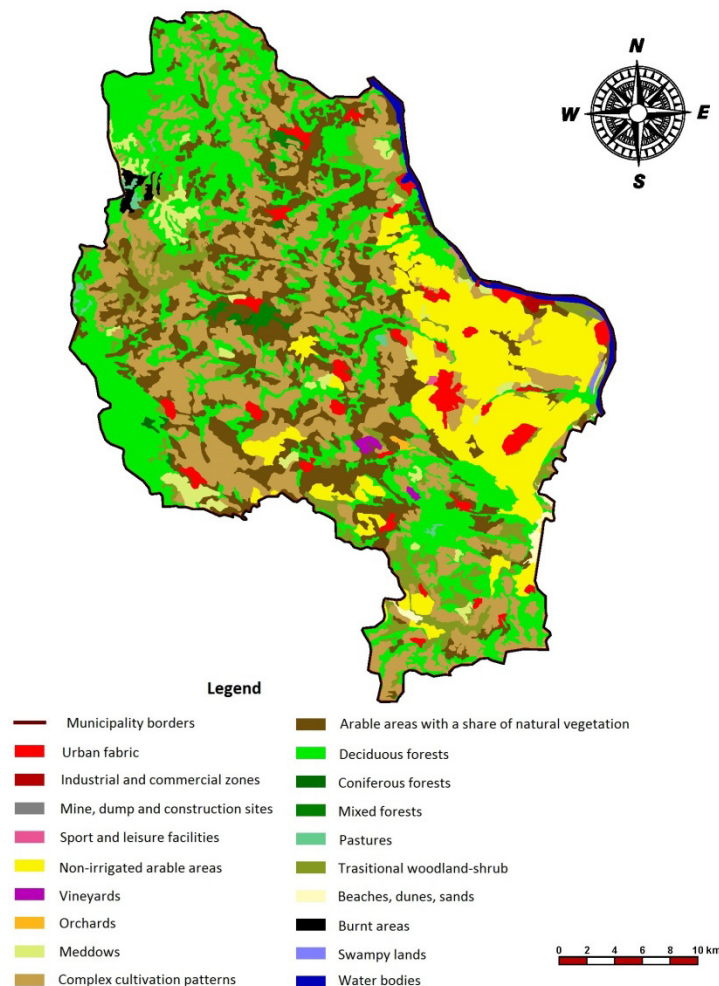


Figure 3: Land use map

With 3 maps presented, the map of protected natural assets and landslides is also considered as an elimination factor for the construction of solar power plants. Beware open data [7] were used for landslides. Terrains made of Neogene sediments are particularly threatened by deep and large land-slides, which have been reactivated in recent years and which are an increasing problem for the old, and especially newly constructed facilities of different purposes [8]. These areas are not suitable for the construction of power plants.

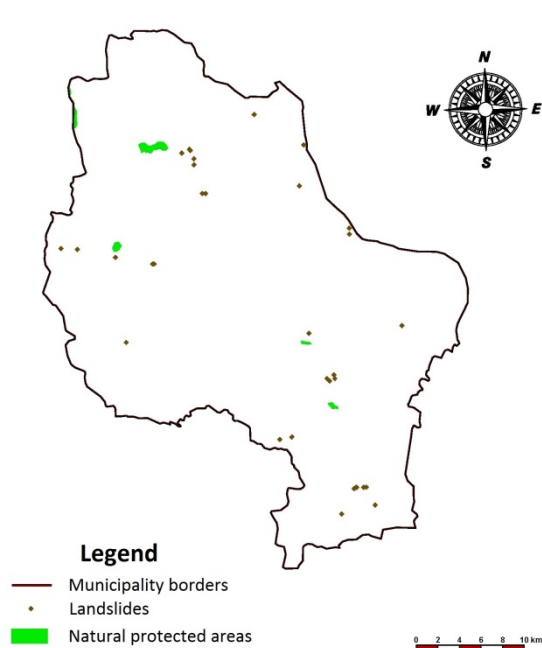


Figure 4: Map of protected areas and natural hazards (landslides)

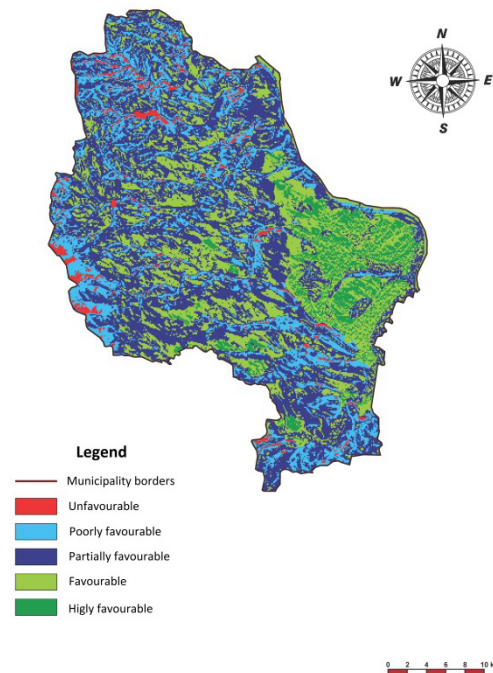


Figure 5: Synthetic map of suitability

Based on processing previous analytical maps and studies of natural conditions, a synthesis map of the suitability of locations for construction of solar power plants in the municipality of Negotin is obtained. The most suitable locations are the areas in the eastern part of the municipality, where several power plants could be built to generate enough electricity for the entire municipality.

Table 3: Evaluation of site suitability

| Rating | Surface area (km ²) | Share in the total surface area (%) |
|--------------------|---------------------------------|-------------------------------------|
| Unsuitable | 28,01 | 2,58 |
| Barely suitable | 201,18 | 18,54 |
| Partially suitable | 496,39 | 45,74 |
| Suitable | 288,21 | 26,56 |
| Extremely suitable | 71,38 | 6,58 |

Solar photovoltaic panels play an extremely important role in electrical energy production in many countries [9].

Table 4: The capacity of the existing and potential solar power plant in Serbia

| Municipalities | Kladovo | Negotin |
|-------------------------------|--------------|----------|
| Installed power | 2 MW | 25,11 MW |
| Surface area | 4,5 ha | 55 ha |
| Number of photovoltaic panels | Approx. 8400 | 96600 |

The table shows the capacity of the existing power plant in Kladovo and the capacity of a potential solar power plant in Negotin. Based on the surfaces obtained from GIS, it was determined that 359.59 km² of the area are suitable and extremely suitable for the construction of power plants, so this area will be taken as available for the application of solar energy. Direct conversion of solar into electrical energy, the so-called photovoltaic effect, was observed almost two centuries ago, but only by

the development of quantum theory in the early 20th century this phenomenon was explained and understood [10]. In the Municipality of Negotin, for the 100% RES-based power supply, 3 solar power plants of 25.11 MW capacity are required, yielding a total power of 75.34 MW.

Photovoltaic conversion of solar radiation takes place in PV solar cells made of semiconductor materials [11]. The power of the photovoltaic panel (PV) would be 260 Wp. Single large solar power plant with a capacity of 75.34 MW can also be built, but in this case, the environmental impact would be much higher (high temperatures) than with separate power plants. According to data from 2011, 11,338 families live in the municipality [12], which means that 6.65 kW of active power would be available per family and should meet their needs. The surface area of all 3 power plants would not be more than 200 ha (2 km²), which is an extremely small percentage compared to the suitable areas obtained from GIS. This means that it would be possible to build more power plants that would supply electricity to other municipalities in the Bor administrative district. The investment in the power plant complex would amount to between 70 and 80 million euros. Construction costs could be covered partly by the Republic of Serbia and partly by developed countries' organizations which expressed readiness to allocate significant resources (up to \$ 100 billion annually) to assist developing countries and their transition to clean energy at a conference in Copenhagen in 2009 [13].

4 Conclusion

The potential of solar energy use in the municipality of Negotin is remarkably high. In addition to the municipality of Negotin having conditions and suitable areas for 100% electricity supply from RES, power plants that would be built in Negotin could also partly supply other municipalities in the Bor administrative district. It is necessary to make an environmental impact assessment and build more power plants of smaller capacities instead of one large precisely for ecological reasons. The construction of these power plants would greatly reduce air pollution caused by the use of fossil fuels, mainly coal in Serbia. Investments are not small but can prove cost-effective i.e. economically justified over time. By building not only solar power plants but also other types of RES, Serbia would significantly save its coal reserves, preserve a large land surface area, improve air quality and contribute to the sustainable development concept.

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