BIBLID 0350–1426 (206)
https://doi.org/kghc.026.55.3.43

Potencijal solarnih fotonaponskih sistema postavljenih na otvorenim parkiralištima Grada Kragujevca

Potential of solar photovoltaic systems installed on open parking lots in the City of Kragujevac

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Ključne reči:
energetski potencijal; otvorena parkirališta; energetska održivost; SketchUp; EnergyPlus; simulacije

Ova tema je značajna jer se bavi racionalnim korišćenjem urbanih površina i primenom obnovljivih izvora energije, što doprinosi smanjenju zagađenja i energetskoj održivosti gradova. Cilj rada je da se utvrdi energetski potencijal prostora za parking i mogućnost njihove upotrebe za proizvodnju električne energije pomoću fotonaponskih sistema. U istraživanju su identifikovana parkirališta u Kragujevcu, a nakon odabira fotonaponskog panela iz kataloga izrađeni su geometrijski i energetski modeli solarnih sistema u SketchUp-u i EnergyPlus-u za sve lokacije. Simulacije pokazuju količinu proizvedene energije na svakoj lokaciji i ukazuju da prinos po panelu značajno zavisi od položaja i uslova konkretnog parkinga.

Key words:
energy potential; open parking lots; energy sustainability; SketchUp; EnergyPlus; simulations

This topic is significant because it addresses the rational use of urban areas and the application of renewable energy sources, contributing to reduced pollution and the energy sustainability of cities. The aim of the study is to determine the energy potential of parking spaces and the extent to which they can be used for electricity generation through photovoltaic systems. In the research, parking lots in Kragujevac were identified, and after selecting a photovoltaic panel from the catalog, geometric and energy models of solar systems were created in SketchUp and EnergyPlus for all locations. The simulations show the amount of energy produced at each location and indicate that the output per panel significantly depends on the position and conditions of the specific parking area.

1. Introduction

Population growth projections indicate that the pace of urban development will continue in the coming decades, and that by 2050, around 84% of the world's population will live and work in cities [1]. As the population increases, so does the number of vehicles leading to a growing demand for parking spaces [2]. These areas represent a significant urban potential for the production of electrical energy. In many countries with significant solar resources, installing photovoltaic systems on parking lots has considerable potential, providing cities with an additional option for meeting their carbon footprint reduction targets. Serbia still utilizes a relatively small share of its solar energy potential. It is estimated about 304.5 MW of installed solar capacity for 2025 [3]. Such systems on carports are typically elevated above ground level, enabling the space beneath to remain fully functional for vehicle movement and parking. In the city of Kragujevac, PV panels are installed facing south at a slope angle of about 37.5°, a configuration that ensures the highest average annual electricity production for this location. This study demonstrates the potential amount of electricity that can be generated from solar carports in the selected urban area of Kragujevac.

2. Methodology

A solar carport is a static, rigid, metal frame designed to support solar panels and the equipment used in a grid-tie system. Its construction ensures the correct orientation and slope angle of the panels, while being strong enough to withstand wind, snow and other weather loads. The optimal installation angle of the photovoltaic panels maximizes solar energy use and at the same time should not have a negative visual impact on the environment and prevent shading that could reduce the efficiency of nearby PV panels throughout the day. The carport for installing photovoltaic panels can be single-pitched, double-pitched or arched, with this work focusing on the practical application of single-pitched solar

This paper was presented at the National Student Competition of the Serbian HVAC&R Society, held within the 56th International Congress and Exhibition on HVAC&R, on December 11, 2025, in Belgrade.

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carports [4]. Commercial solar carports typically range in height from 3.5 to 5 m in order to accommodate larger vehicles such as trucks, vans and buses [5]. In this study, a height of 3.5 m was selected for the modeled structure.

Table 1. List of potential parking lot locations in Kragujevac for installing photovoltaic systems

Case	Parking lot location	Cadastra municipality	Plot number
1	FIAT Automobiles Serbia	Kragujevac II	1/39
2	Institute for Health Care of Workers (IHCW)	Kragujevac II	1/4
3	Indoor Swimming Pools (ISP)	Kragujevac III	895/18
4	„Čika Dača" Stadium	Kragujevac III	895/31
5	„21st October" Museum	Kragujevac III	890
6	Second Kragujevac Gymnasium (SKG)	Kragujevac IV	10480/2
7	Elektrošumadija	Kragujevac IV	10413/1
8	METRO	Kragujevac IV	10450/1
9	„Delta Park" Shopping Center (DPSC)	Kragujevac IV	10470/7
10	Palace of Justice	Kragujevac IV	10472/5
11	„Toza Dragović" School of Trade and Hospitality	Kragujevac IV	10475/7
12	University Clinical Center Kragujevac	Kragujevac IV	10486/8
13	Rectorate of the University of Kragujevac	Kragujevac IV	10473/1

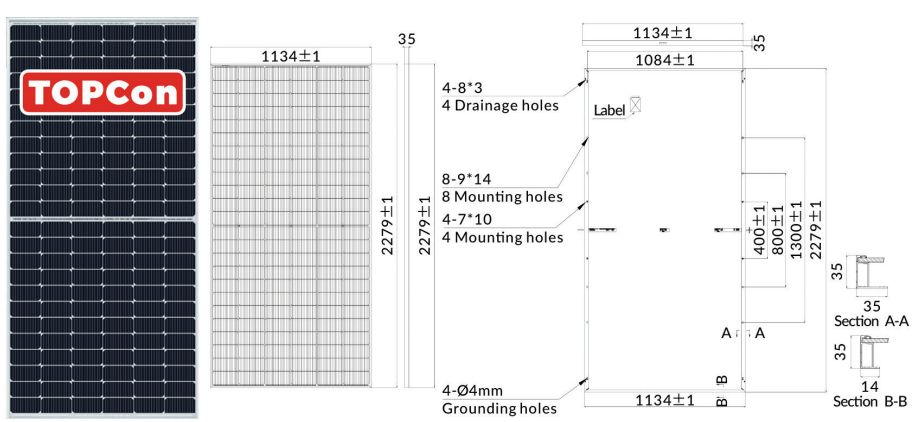
To identify the most suitable parking lots for installing solar photovoltaic systems in Kragujevac, potential locations were first mapped and analyzed based on ownership and spatial characteristics and exposure to sunlight. The analysis focused primarily on open parking areas in public or state ownership, as these locations simplify permitting and allow direct support from local and national institutions within the broader energy transition. Certain privately owned parking areas were also considered with the proposal of cooperation with the city or public companies. Portal Geo Serbia [6] served as the primary source for identifying potential parking areas and for finding the corresponding cadastral municipality and plot number, while detailed verification was carried out through the eCadastre portal of the Republic Geodetic Office [7], where these two identifiers were entered to determine ownership and legal status. By analyzing the territory of the city of Kragujevac using the aforementioned databases and platforms, the locations listed in Table 1 were selected.

Parking areas that are shaded by tall buildings or large trees for most of the day were excluded from Table 1 in the following, as this significantly reduces the availability of solar radiation. In addition, some locations contain surfaces used for parking but are not officially designated as parking lots, meaning they lack basic infrastructure and markings. Due to the limited reliability and irregular updating of data on the Google Earth [8] and Google Maps [9] platforms, which were



Figure 1. Satellite image of the city of Kragujevac from Google Earth [8]; 1 – FIAT Automobiles Serbia, 2 – IHCW, 3 – ISP, 4 – SKG, 5 – Elektrošumadija,, 6 – METRO, 7 – DPSC

used in the process of selecting locations, all locations were additionally verified through on-site field visits in order to confirm the information shown on the platforms. A comparison between the on-site conditions and the satellite imagery shows notable differences, especially in relation to trees. On satellite images, trees often appear more numerous, larger, or denser, while field inspection revealed that their number is smaller and that their shading effect is not as significant



Electrical parameters			Temperature parameters	
Value	Standard conditions	Nominal conditions	Value	Real conditions
Maximum power, P_{max}	585 W	411 W	Nominal Operating Temperature	45°±2°
Open Circuit Voltage, V_{oc}	51.70 V	49.31 V	Temperature Coefficient of P_{max}	–0.29%
Short Circuit Current, I_{sc}	14.40 A	11.63 A		
Voltage at Maximum power, V_{mpp}	43.24 V	40.05 V	Temperature Coefficient of V_{oc}	–0.25%
Current Maximum Power, I_{mpp}	13.53 A	11.01 A		
Module efficiency	22.64%		Temperature Coefficient of I_{sc}	+0.045%

Figure 2. Visual appearance and technical specification sheet of the selected PV panel together with table of electrical and temperature parameters from manufacturer's catalog [10]

as it appears in the images. If trees on parking surfaces obstruct the installation of solar carports, their transplantation may be considered. The selected locations are shown in Figure 1 and in the following section of this paper each chosen location is observed individually for the purpose of determining its solar photovoltaic potential.

For this study, an N-type LUXEN 585W photovoltaic panel was selected [10]. The dimensions of the panel are 2279 mm × 1134 mm × 35 mm. Figure 2 shows the panel along with a table of its electrical and temperature parameters.

The PVGIS tool [11] was used to optimize the panel slope angle, while the azimuth for each parking lot location was determined in Google Earth to ensure correct orientation: –90° east, 0° south, +90° west. SketchUp [12] was used to develop precise 3D models of the parking lots in Kragujevac and to visualize the placement of photovoltaic carports. These models, including both surrounding buildings and carport structures, were organized within the "Shading Surface Group" to accurately represent shading effects and spatial layout, and were aligned with true cardinal directions to ensure realistic solar simulations. Figure 3 shows the modeled locations and carport designs.

After completing the modeling of locations in the SketchUp program, with the help of the OpenStudio extension, they are converted into an IDF document that is opened in the EnergyPlus program [13]. A weather file for the city of Kragujevac was also attached, which contains data on temperature, humidity of the outside air, wind speed and direction, solar radiation and precipitation. The next step involved filling the classes in EnergyPlus where other parameters, such as electrical and temperature parameters shown in Figure 2, are defined. Finally, simulations were run to determine the annual electricity production of the photovoltaic modules installed at selected locations.

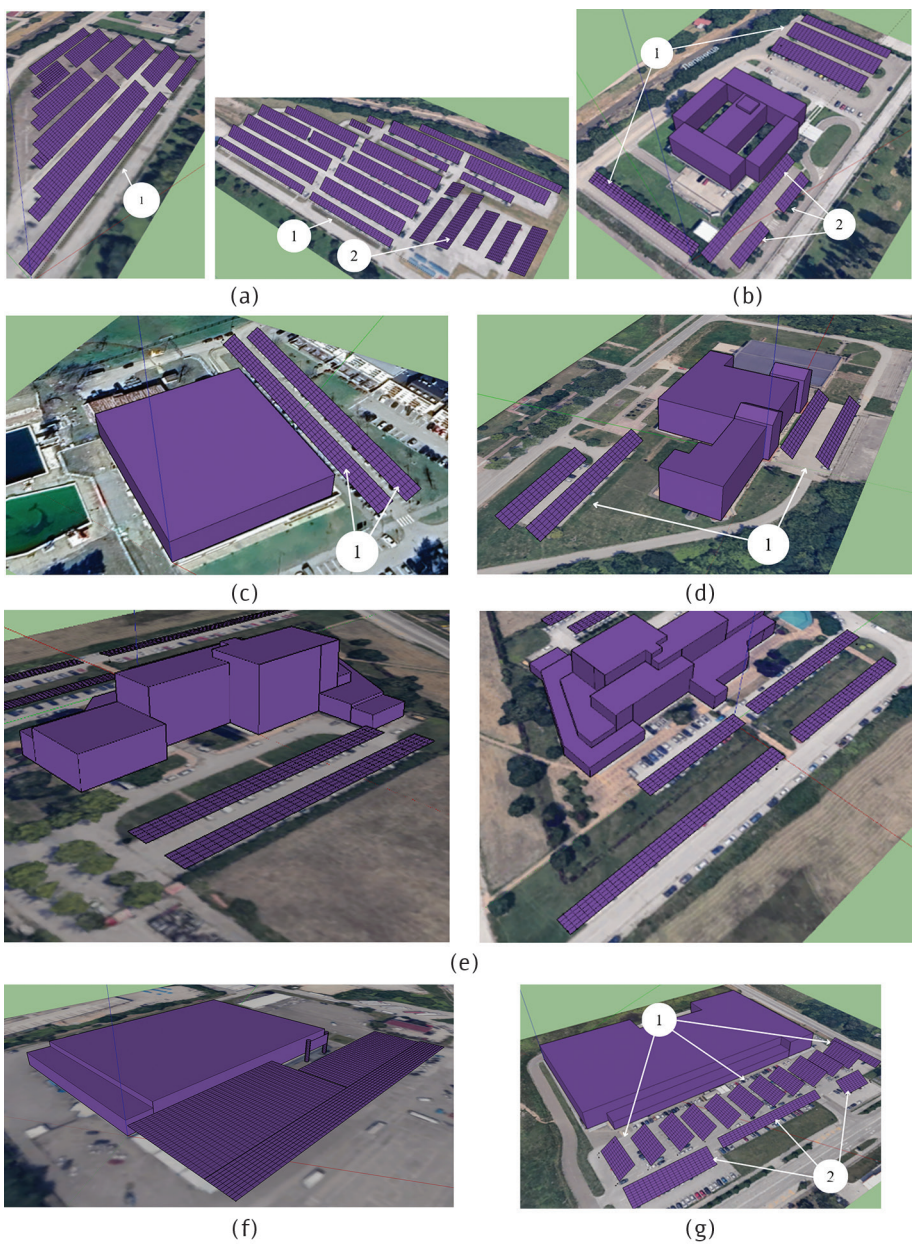


Figure 3. Layout of solar carports on selected locations with the surrounding buildings; (a) FIAT Automobiles Serbia (1 – slope angle of 36°, 2 – slope angle of 18°), (b) IHCW (1 – slope angle of 18°, 2 – slope angle of 36°), (c) ISP (1 – slope angle of 33°), (d) SKG (1 – slope angle of 36°), (e) Elektrošumadija (left: slope angle of 0°, right: slope angle of 3°), (f) METRO (slope angle of 0°), (g) DPSC (1 – slope angle of 33°, 2 – slope angle of 27°)

3. Results

An overview of the key parameters of the installed solar carports and the corresponding simulation results are shown in Table 2. In real conditions, photovoltaic systems experience technical losses caused by inverter inefficiencies, cable resistance, connector limits, temperature effects, and voltage drops. Therefore, a 10% reduction was applied to the simulated results to provide a more realistic estimate of actual energy production. The parking area within the "FIAT Automobiles Serbia" complex represents the largest analyzed surface in this study and the location with the highest number of PV panels. Although the orientation of the parking area at location of „Elektrošumadija" is nearly ideal, facing south, as in the case of the „Second Kragujevac Gymnasium", the photovoltaic panels were oriented east on the right side of the structure and west on the left side for the sake of installation simplicity. The "METRO" parking area differs from the other locations because part of it is already covered by a flat roof, which offers a stable base for installing photovoltaic panels. The concept is to extend this roof over the remaining open spaces, creating a continuous flat surface suitable for horizontal (0°) PV installation.

The diagram in Figure 4 compares the annual electricity production of all seven analyzed locations. The „FIAT Automobiles Serbia" site clearly stands out with the highest yield due to its large available area, while locations like „METRO" and „DPSC" also achieve considerable production. Smaller areas or shading at sites such as the „IHCW", „ISP", „SKG" and „Elektrošumadija" result in lower totals.

Table 2. Key characteristics of the installed solar carports and their simulation results

Location	Orientation [°]	Slope angle of PV panels [°]	Total number of PV panels by orientation	Total number of PV panels	PV panel area by orientation [m²]	Total PV panel area [m²]	Electricity generated per PV panel [kWh]	Total annual electricity production [kWh]
FIAT Automobiles Serbia	–20	36	6 111	6 957	15 793.18	17 979.57	795.033	5 219 354.376
	70	18	846		2 186.39		705.969	
Institute of Health Care for Workers	–20	36	182	892	470.36	2 305.27	795.033	642 034.152
	70	18	710		1 834.91		705.969	
ISP	30	33	430	430	1 111.29	1 111.29	798.651	314 573.427
SKG	5	36	410	410	1 059.6	1 059.6	815.895	324 728.091
Elektrošumadija	–87	3	560	880	1 447.26	2 274.26	663.885	573 054.39
	93	0	320		827		664.254	
METRO	–60	0	2 254	2 254	5 825.21	5 825.21	665.487	1 466 979.453
"Delta Park" Shopping Center	30	33	1 115	1 517	2 881.59	3 920.51	798.651	1 111 558.266
	–60	27	402		1 038.92		704.592	

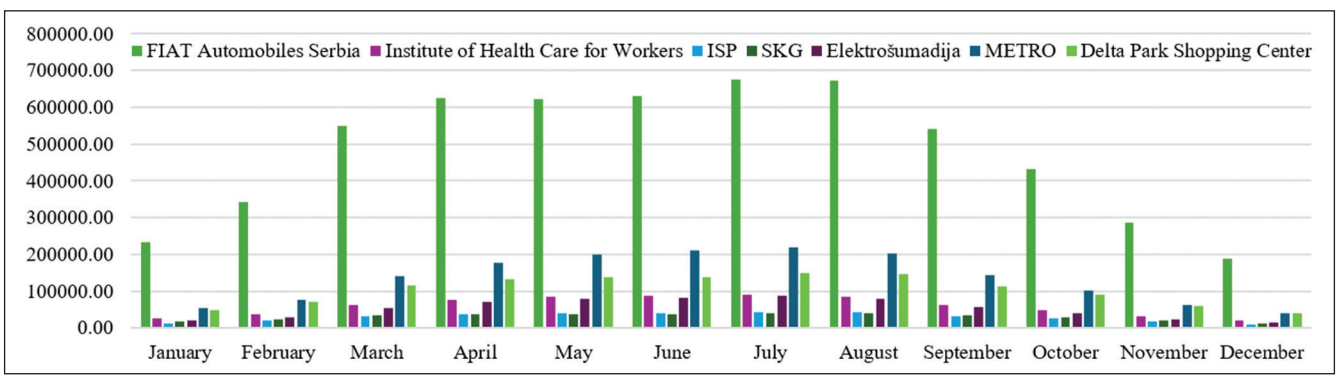


Figure 4. Monthly electricity production at the analyzed locations [kWh]

Figure 5 presents electricity produced per panel, calculated by dividing the total energy generated at each location by the number of installed panels on that location, showing that the „Second Kragujevac Gymnasium" achieves the highest value (792 kWh/panel) thanks to optimal orientation and slope angle, similar to ideal for Kragujevac. In contrast, locations with horizontal or nearly horizontal panels, such as „METRO" (650.83 kWh/panel) and „Elektrošumadija" (651.2 kWh/panel), record the lowest yields. The „METRO" location records the lowest per-panel yield, producing approximately 17.8% less energy than the „SKG". These results demonstrate that orientation, slope angle and shading strongly affect panel performance and help identify the most suitable locations for solar installations.



Figure 5. Average electricity production per PV panel at the analyzed locations [kWh/PV panel]

During the summer break, electricity consumption at the "Second Kragujevac Gymnasium" decreases sharply, while cooling demand is minimal and PV production reaches its annual peak, creating significant energy surpluses. In contrast, heating demand during the winter can contribute to higher electricity use. This highlights opportunities to optimize energy use and consider storage or feeding excess electricity into the grid.

4. Conclusion

The total electricity production is primarily influenced by three key factors: the orientation and slope angle of the panels, the available parking area, i.e. the number of panels that can be installed and the presence of shading caused by trees and nearby buildings. The results identify the most technically suitable parking lots for solar carports, based on reliable but idealized software simulations that help compare locations and predict system performance. This study can serve as a model for other cities, requiring only minimal adjustments to evaluate the solar potential of their own carport locations. Parking areas represent large and not fully used surfaces that, due to their size and accessibility, hold significant potential to become an important part of the local sustainable energy system.

5. Acknowledgements

This work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, under contract no. 451-03-34/2026-03/200107, dated February 5, 2026.

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