FACTA UNIVERSITATIS
Series: **Automatic Control and Robotics** Vol. 23, Nº 2, 2024, pp. 111 - 121
https://doi.org/10.22190/FUACR241028008P

Regular Paper

DESIGN AND OPTIMIZATION OF SOLAR PARKING CANOPY AS A PART OF ENERGY EFFICIENT URBAN PLANNING

UDC (621.383.51:622.7.012)

Aleksandar Pantić, Adriana Petković, Sanja Aleksić

University of Niš, Faculty of Electronic Engineering,
Department of Microelectronics, Republic of Serbia

ORCID iDs: Aleksandar Pantić https://orcid.org/0000-0003-2351-498X
Andriana Petković https://orcid.org/0009-0007-0453-8704
Sanja Aleksić https://orcid.org/0000-0003-4414-6442

Abstract. *This paper proposes the optimal use of available space on canopies of parking spaces in urban areas for the installation of low and medium power photovoltaic systems and electricity production. Simulations show that a PV1 system offers a return on investment of 187% with a payback period of 5.6 years, while a PV2 system achieves an ROI of 91.9% with an 8.4-year payback. These findings emphasize the cost-effectiveness and environmental benefits of solar parking canopies in urban planning. The obtained electricity could be used to power nearby residential and business premises or electric car chargers. Also, there is a possibility of direct injection of produced electricity into the distribution network. Two configurations of the photovoltaic system at a specific location were analyzed in order to find the optimal solution in terms of the relationship between the price of the system, the electricity produced and the time required to return the investment. The program PVsyst was used for the design and optimization of photovoltaic systems. The obtained simulation results for both proposed photovoltaic systems are presented and compared.*

Key words: *Solar energy, PV system, parking, canopy, urban planning.*

1. INTRODUCTION

Population growth projections indicate that by 2050. over 70% of the global population will live and work in cities since metropolitan development will continue progressing in the upcoming decades [1]. The continuous temperature increases in the urban areas, affected by rapid urbanization and undeniable climatic change, are escalating the energy problem of cities and intensifying the pollution problems. The mainimpact of cities on the local

Received October 28, 2024 / Accepted December 19, 2024
Corresponding author: Aleksandar Pantić
University of Niš, Faculty of Electronic Engineering, Department of Microelectronics, Aleksandra Medvedeva 4, 18104 Niš, Republic of Serbia
E-mail: aleksandar.pantic@elfak.ni.ac.rs

weather is the Urban Heat Island (UHI). Parking lots arelarge pavement surfaces that absorb the sun's energy and retain heat, therefore contributing to the UHI effect. The number of spaces per vehicle is rising as the adult population has become more dependent on cars; thus, a large portion of the urban environment is dedicated to parking lots. Installing a solar canopy over an existing parking lot is a more efficient use of the duplicate square footage and could turn an open pavement surface into a significant electricity generator. Solar energy, as renewable energy, is seen as a necessary step toward sustainable energy development, reduction of fossil fuel usage, and mitigation of climate change.

Public spaces are the structural elements of any architectural environment, areas of social cohesion, spaces of coexistence and outbreaks of urbanity programmatically designed to attract all types of publics, reunite the citizens of the city, and improve the dynamics of the urban space; in one word, the city's front window. The quality of urban space is primarily determined by the quality of the public areas belonging to the city, the areas that the city offers for common use to its inhabitants. Architecture and reason usually go together: we build for a specific purpose, for specific functions; we use materials and methods that are directly related to the situations in which we need to interfere; we calculate, anticipate, and ensure as much as possible that our interventions in the public space will be used in the way that we have imagined. But what would happen if we did not have these motivations? If we would only build to change the image of the city, to renew the relationship between man and architecture. Can we rebuild so that we sublimate our present experience? This paper proposes an incursion that provides an answer to these actions: to build, beautify, regain, experience, plan, perceive, criticize, program, and transform our relationship with architecture and the city. These actions, with their possible variations and associated ramifications, are the main directions or, rather, the effects of small landscape designs in the lost or forgotten spaces of the city. This paper also, in addition to all the above, offers a solution on how to optimally and efficiently use the existing space on the canopies of the parking lot to install photovoltaic systems and obtain electricity.

Solar radiation reaching the Earth's surface is estimated at about 190 million TWh annually. This energy is about 170 times greater than the total reserves of coal worldwide and, compared to the energy needs of humankind, which amount to 130 thousand TWh annually [2]. Serbia has an average of 272 sunny days and about 2300 sunny hours. The average daily energy of global radiation, in the territory of the Republic of Serbia ranges from 1,1 kWh/m² in the north to 1,7 kWh/m² in the south during the winter period, while for the summer period, it ranges from 5,9 kWh/m² in the north to 6,6 kWh/m² in the south. Annually, the average value of the overall sun radiation for the territory of the Republic of Serbia ranges from 1200 kWh/m² in northwest Serbia to 1550 kWh/m² in southeast Serbia, while in the middle part, it is about 1400 kWh/m² (Fig. 1 (left)). Therefore, our Nisava region has very great potential when it comes to the use of solar energy for electricity production. It is estimated that the value of specific photovoltaic power output (PVOUT), which represents yearly average values of photovoltaic electricity delivered by a PV system and normalized to 1kWp of installed capacity, ranges from 3,22kWh/kWp to 3,77kWh/kWp (Fig. 1 (right)) [3].

It is obvious that solar radiation in Serbia and our region is about 40% higher than in the countries in European Union, but we are still significantly behind in terms of installed photovoltaic capacities. This gives us great opportunities to replace fossil fuels in the coming period and start getting significant amounts of electricity from medium and small photovoltaic power plants.

2. Benefits of Utilization of Solar Energy

Renewable energy is seen as the solution for managing both increasing electricity demand and environmental sustainability. Solar canopies are an innovative way to maximize an existing space for multiple purposes and benefits. Photovoltaics are seen to be generally of benign environmental impact, generating no noise or chemical pollutants during use. It is one of the most viable renewable energy technologies used in an urban environment, replacing existing building cladding materials [4]. The University of Kansas predicted electricity production with close to zero emissions [5], meaning no CO_2, NH_4, or N_2O was produced. In their research, the most significant effect of PV parking spots was reducing carbon dioxide (CO_2) emitted by the University. It was estimated that the University would save 2.5 metric tons of CO_2 emissions per year for each covered parking space. The CO_2 emission reductions in methane (NH_4) and nitrous oxide (N_2O) of metric tons and 0.03 metric tons would also occur, chemicals known to cause acid rain and increase global warming.

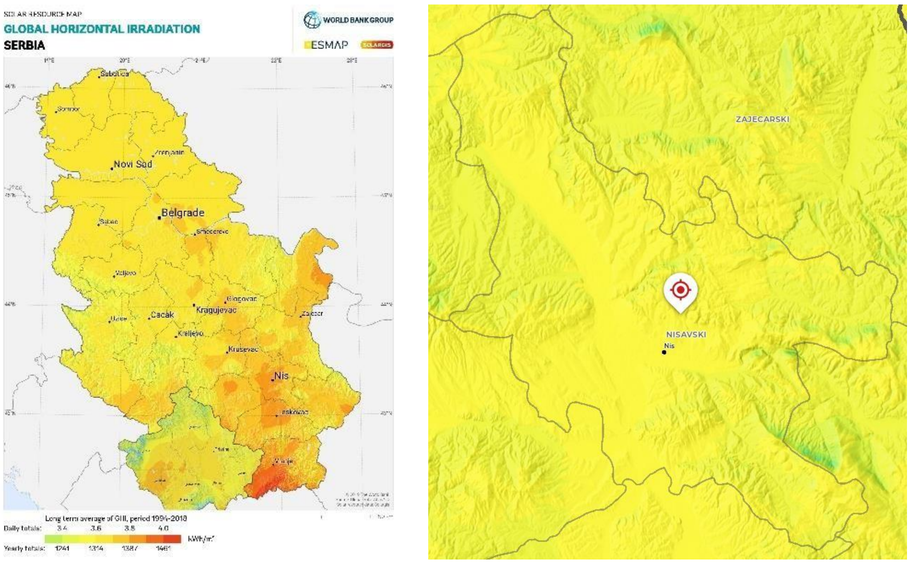

Fig. 1 Global horizontal irradiation (GHI) for the Republic of Serbia (left), andspecific photovoltaic power output (PVOUT) for Nisava region (right) [3,4]

Furthermore, UHI leads to greenhouse gas emissions and increased summer peak energy demands and that could be mitigated by installing solar parking canopies. Solar panels absorb solar energy to produce energy used in buildings. During this process, they modify the energy balance of the urban surface in contact with the atmosphere and thus influence the urban micro-climate. A scenario of large but realistic deployment of solar panels in the Serbia urban area was simulated in the research [6], and the results showed a reduction in the UHI of 0.2 K by day and up to 0.3 K at night. Also, in the same study, it was calculated that for the summer period, the solar panels reduced the energy needed for air-conditioning by 12%. Since the UHI effect is most pronounced during summer peak power demands, the applied PV panels to mitigate is beneficial for the amount of power produced by the PV panels.

One of the apparent benefits considering the solar parking canopy is the shade provided by the solar panels covering the vehicles. Shade considerably reduces the vehicle temperature during the day, protecting it from sun damage, such as paintwork damaged or cracked and warped interiors during the hot summer period. In a typical parking lot, a car is subjected to direct sunlight exposure in the spring and summer months. According to the Centers for Disease Control and Prevention, if the temperature reaches 27°C or more, the temperature inside a vehicle can quickly climb between 37°C to 54°C degrees. The research [7] shows that at 35°C, the energy consumption would increase from 2% to 70% and that these increases were due to the extra energy required to run the air-conditioning system to maintain 22°C cabin temperatures. These increases in energy consumption depended on the air-conditioning system type, powertrain architecture, powertrain capabilities, and drive patterns. The more efficient the powertrain, the more significant climate control (heating or cooling) impact on energy consumption.

Additionally, lower internal temperature provides more comfort for drivers entering the car after sun exposure and reduces their heatstroke risk. As the survey shows [8], drivers perceive shade as a valuable parking lot asset. Furthermore, the solar parking canopy could protect from both rain and snow.

3. Simulation Results

In this paper, we consider the possibilities of realizing a photovoltaic power plant in the electrical engineering school "Nikola Tesla" parking lot (Fig. 2 (left)), whereby solar panels would be placed on the canopy of the parking lot. The cross section of the canopy structure is shown in the fig. 2 (right). City of Niš is situated in the southern and eastern Serbia region at the 43°19' latitude north and 21°54' longitude east, at about 200 meters above sea level, in the Nišava region.

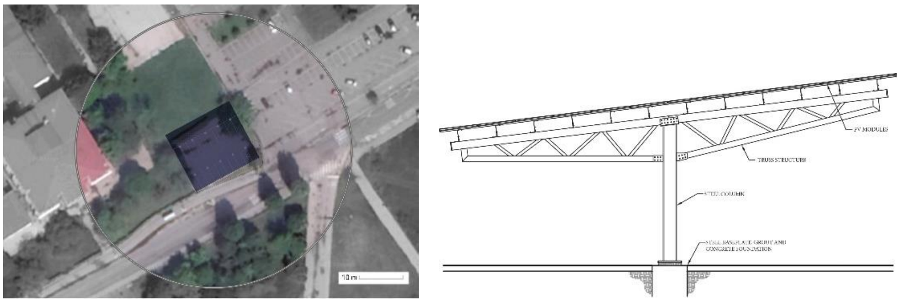

Fig. 2 Location of high school "Nikola Tesla" Niš parking lot and proposed solarcanopy (left), and potential truss canopy construction (right)

There are no visible markings for parking places, and the concrete suffered mechanical damage over time. Groundwork, reconstruction of the car access is suggested, and the formation of 20 parking spaces. The 90° parking angle would provide the most parking spaces for a given area, two rows with ten parking spaces each, divided by two- way traffic flow. The pedestrian zone is designed in the north part of the lot, making the straight line to the High School entrance plane. A truss canopy is proposed for a solar mounting canopy structure. Two, five columns, solar canopies are designed with a length of 24m and a width of 9m for ten cars in a row. A total of 432 m² of space is at the solar canopy shade.

By analyzing the situation on the ground, we can see that the orientation of the parking lot and the canopy on it deviates from the ideal, which would allow maximum use of available solar radiation. Provided that the construction of the parking canopy is monitored, the solar panels would be placed at an angle of -23° azimuth angle facing south, while the elevation slope would be 10° slope, which corresponds to the slope of the canopy structure.

3.1. Case studies configuration and simulation

As already indicated, we will design two variants of the photovoltaic system, where in the first case study, PV1, cheaper solar panels of lower power are used, while in the second case study, PV2, more expensive solar panels of higher power are installed. The goal is to determine which configuration will be more favorable, both in terms of the total required investment, and in terms of the amount of electricity produced and the time of return on investment. The characteristics of the used solar panels are given in Table 1.

Table 1 Solar panel characteristics

Solar panel	PV1	PV2
Model	GCL-M3/60GDF	GCL-M3/72GD
Manufacturer	GLC	GLC
Technology	Si-mono	Si-mono
Nominal power	300 Wp	400 Wp
Short-circuit current	9.48A	10.28A
Open-circuit voltage	39.80V	49.20V
Efficiency	20.07%	22.25%
Dimension	1706×1006mm	2030×1000mm
Weight	25,90kg	28,20kg
Price	195€	250€

Solar panels based on the technology of the monocrystalline Si renowned manufacturer GCL System Integration Technology Co. Ltd were used. Both used solar panels are newer generation products, have very good characteristics and are available on our market. Photovoltaic system (PV) configuration and preliminary simulations were done in PVsyst software tool. This software tool offers a large database with meteorological data for our location, as well as a large selection of PV system elements. Perspective of the PV-field and surrounding shading scene are defined using the PVsyst program which is shown in fig. 3. The

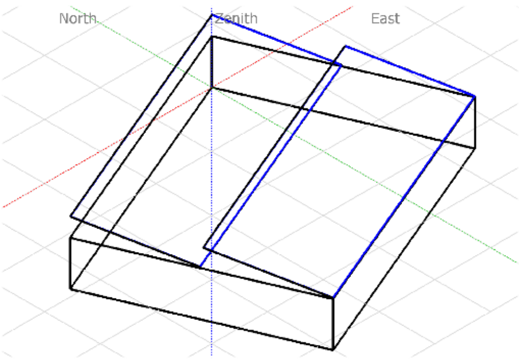

Fig. 3 Perspective of the PV-field and surrounding shading scene

deviation of the constructed PV field from the optimal orientation to the south can be clearly seen.

Fig. 4 shows an iso-shadings diagram for our location that shows the trajectory of the Sun for characteristic dates during the year, as well as losses due to shading, which are, as can be seen, most present during the winter months.

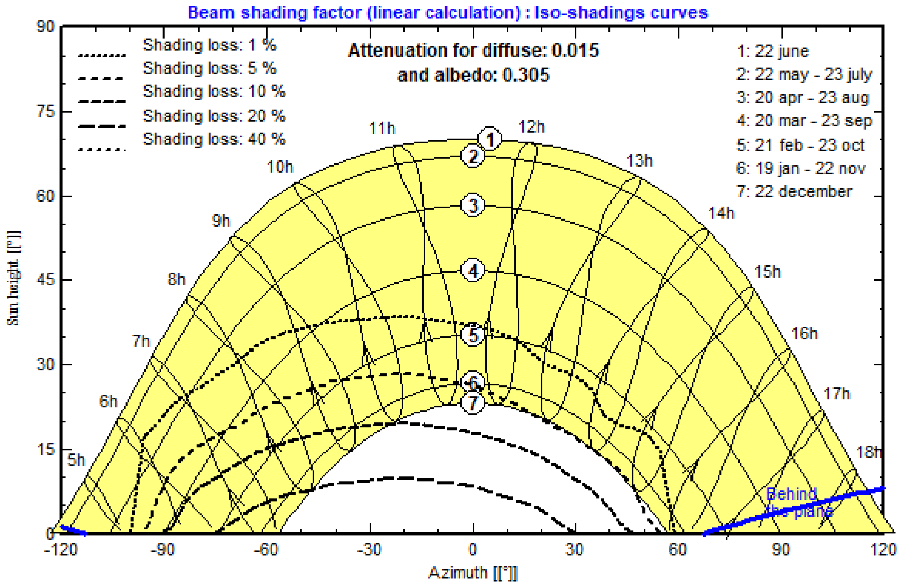

Fig. 4 Iso-shadings diagram

The first designed and optimize photovoltaic system PV1 used mono-Si solar panels GCL-M3/60GDF-300. PV1 system consists of 247 PV modules (string with 13 modules in series and 19 strings in parallel) with total area of 424 m^2 where the effective area of solar cells is 370m^2. Global nominal power (STC) of PV1 system is 74,1 kWp, whereby under normal operating conditions at 50°C the power of PV1 is 67,2 kWp. In this system we use 6 inverters, Sunny Boy 10000TLUS-12-240 produced by SMA Energy System, with the nominal power of 10 kW and operating voltage between 345 and 480 V. Balances and main results (GlobHor - horizontal global irradiation, DiffHor - horizontal diffuse irradiation, T_Amb - average temperature, EArray - effective energy at the output of the array, E_User – energy supplied to the user, E_Solar – energy from the sun, E_Grid – energy injected into grid), by months, obtained by the simulation are given in the table 2. Thedesigned photovoltaic system PV1 would produce about 92 MWh of electricity per year, and as can be noticed, photovoltaic system provides the school with a significant amount of electricity, and in addition, a good part of the produced energy is delivered to the electricity distribution network. Monthly normalized production (per installed kWp) of PV1 is shown in the fig. 5. As can be expected, the system provides the most energy in the period from March to October, while in the winter months the production of electricityis somewhat lower.

Table 2 Balances and main results for PV1 system

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_User	E_Solar	E_Grid	EFrGrid
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	kWh	kWh	kWh
January	49.8	25.60	0.61	60.0	55.3	3892	9150	2284	1465	6865
February	59.0	32.53	2.37	67.0	63.3	4548	9150	2657	1745	6493
March	104.9	57.05	7.71	114.2	108.8	7662	9139	3429	4045	5710
April	142.5	64.31	12.21	150.0	144.2	9805	9150	3959	5631	5191
May	162.2	79.92	17.58	165.8	159.1	10567	9150	4178	6148	4971
June	184.3	84.04	20.16	185.8	178.4	11728	9150	4598	6880	4552
July	197.0	79.05	22.77	200.4	193.0	12439	9150	4460	7726	4690
August	169.6	67.78	22.65	177.5	171.0	11115	9150	4180	6706	4970
September	126.6	50.72	16.69	137.6	132.0	8878	9150	3750	4934	5400
October	90.7	40.77	12.66	103.6	98.4	6697	9150	3070	3453	6079
November	54.6	27.43	6.85	65.6	60.6	4186	9150	2459	1585	6691
December	37.8	22.76	2.31	45.5	41.6	2918	9150	1970	814	7180
Year	1379.3	631.94	12.11	1473.0	1405.7	94435	109787	40994	51131	68792

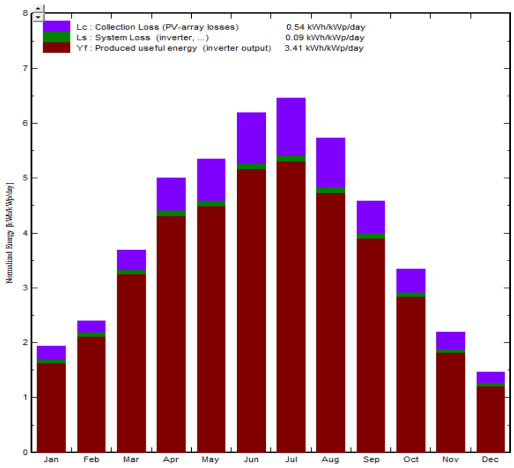

Fig. 5 Monthly normalized production (per installed kWp) of PV1.

The second designed and optimized photovoltaic system PV2 used mono-Si solar panels GCL-M3/72GD-400. PV2 system consists of 210 PV modules (string with 15 modules in series and 14 strings in parallel) with total area of 426 m^2 where the effective area of solar cells is 378m^2. Global nominal power (STC) of PV2 system is 84,0 kWp, whereby under normal operating conditions at 50^{o}C the power of PV1 is 76,0 kWp. In this system we use 3 inverters, Sunny Tripower 25000TL-JP-30 produced by SMA Energy System, with nominal power of 25 kW and operating voltage between 390 and 800 V. Balances and main results, by months, obtained by simulation are given in the table 3, while the monthly normalized production (per installed kWp) of PV2 is shown in the fig. 6.

The designed photovoltaic system PV2 would produce about 107 MWh of electricity per year, which is about 15 MWh more than the photovoltaic system PV1. Monthly normalized production (per installed kWp) of PV2 is shown in the fig. 6.

Table 3 Balances and main results for PV2 system

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_User	E_Solar	E_Grid	EFrGrid
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	kWh	kWh	kWh
January	49.8	25.60	0.61	60.0	54.3	4372	9150	2425	1873	6725
February	59.0	32.53	2.37	67.0	62.6	5001	9150	2770	2148	6380
March	104.9	57.05	7.71	114.2	108.2	8604	9150	3556	4909	5594
April	142.5	64.31	12.21	150.0	143.9	11199	9150	4082	6922	5068
May	162.2	79.92	17.58	165.8	159.0	12094	9150	4324	7553	4826
June	184.3	84.04	20.16	185.8	178.2	13404	9150	4735	8430	4415
July	197.0	79.05	22.77	200.4	192.8	14247	9150	4584	9397	4566
August	169.6	67.78	22.65	177.5	170.8	12675	9150	4288	8159	4862
September	126.6	50.72	16.69	137.6	131.4	10027	9150	3852	6002	5298
October	90.7	40.77	12.66	103.6	97.3	7464	9150	3190	4147	5960
November	54.6	27.43	6.85	65.6	59.6	4636	9150	2580	1978	6569
December	37.8	22.76	2.31	45.5	40.9	3199	9150	2109	1030	7041
Year	1379.3	631.94	12.11	1473.0	1399.1	106923	109797	42495	62548	67302

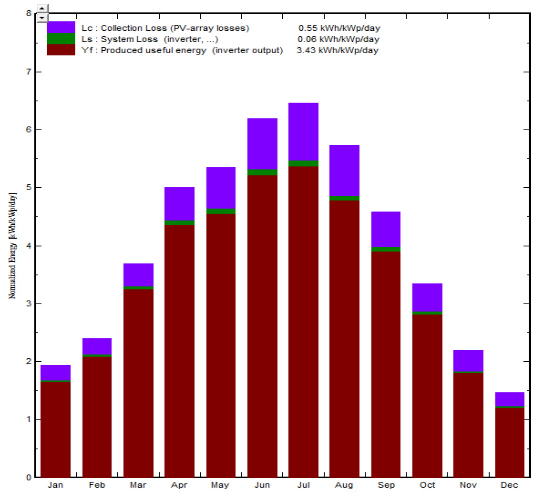

Fig. 6 Monthly normalized production (per installed kWp) of PV2

3.2. PV canopies comparison and techno-economic analysis

The obtained simulation results of both photovoltaic systems show the justification of the investment. Of course, it is necessary to make a choice between these two systems, depending on the given conditions and circumstances. Therefore, we will first compare their characteristics. A comparison of the obtained simulation results for photovoltaic systems PV1 and PV2 is given in Table 4. We compared the effective energy that photovoltaic systems provide E Array, the amount of electricity we supply to distribution network E Grid, as well as their performance ratio PR, which in fact represent a measure of the quality of a PV system that is independent of location and it therefore often described as a quality factor. It is clear that these are PV systems with similar characteristics. Thereby photovoltaic system PV2 produces slightly more electricity and has a better performance ratio.

Table 4 Comparison of the simulation results for case studies PV1 and PV2

	PV1			PV2		
	E_Array [MWh]	E_Grid [MWh]	PR [ratio]	E_Array [MWh]	E_Grid [MWh]	PR [ratio]
January	3.89	1.465	0.877	4.37	1.873	0.929
February	4.55	1.745	0.870	5.00	2.148	0.920
March	7.66	4.045	0.851	8.60	4.909	0.901
April	9.80	5.631	0.830	11.20	6.922	0.881
May	10.57	6.148	0.792	12.09	7.553	0.847
June	11.73	6.880	0.785	13.40	8.430	0.841
July	12.44	7.726	0.765	14.25	9.397	0.823
August	11.11	6.706	0.775	12.67	8.159	0.833
September	8.88	4.934	0.800	10.03	6.002	0.854
October	6.70	3.453	0.838	7.46	4.147	0.890
November	4.19	1.585	0.852	4.64	1.978	0.905
December	2.02	0.814	0.892	3.20	1.030	0.941
Year	94.44	51.131	0.812	106.92	62.548	0.866

A detailed overview of the prices of photovoltaic system components, design, studies and maintenance, as well as techno-economic evaluation is shown in Table 5. From the attached data, it is obvious that it is more profitable to invest in the first photovoltaic system PV1, despite the fact that it has less installed power. Namely, the price of produced electricity obtained from this system is lower, the return on investment (payback time) is shorter and the net profit is higher, which shows us the ROI (return of investment) index it represents the ratio of realized benefits and total investments. The cumulative cashflow for PV1 and PV2 for the total lifetime of the project is shown in theFig. 7.

Table 5 Economic evaluation

	PV1			PV2		
Investment						
PV modules	247 units	195€	48,165€	210 units	250€	52,500€
Inverters	6 units	2,000€	12,000€	3 units	3,500€	10,500€
Studies and analyses			6,000€		6,500€	
Taxes andsubsidies			12,270€		15,030€	
Net investment			**50,435€**		**68,530€**	
Operating cost per year			3,750€		5,305€	
Cost of produced energy		€/kWh	0.068	€/kWh	0.087€	
Return of investment						
PV lifetime	years		20		20	
Payback	years		5.6		8.4	
Net profit			94,318€		62,962€	
ROI			187%		91.9%	

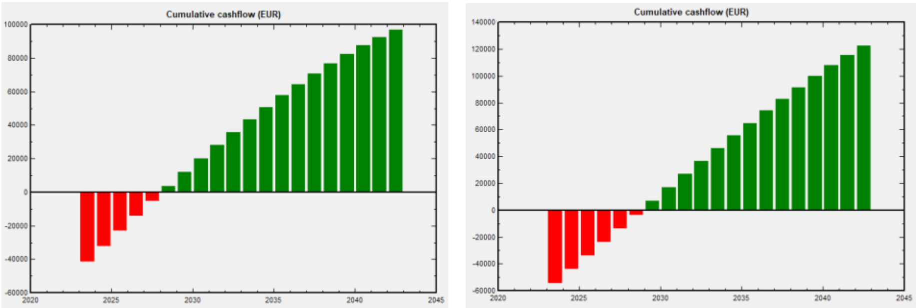

Fig. 7 Cumulative cashflow for PV1 (left) and PV2 (right)

4. Conclusion

This research successfully demonstrates the feasibility and advantages of implementing solar parking canopies as a sustainable solution to urban energy challenges. The analysis of the photovoltaic systems PV1 and PV2 at the parking lot of the Electrical Engineering High School "Nikola Tesla" in Niš highlights their potential to transform an underutilized space into a productive energy source. By leveraging available solar radiation, these systems can generate significant electricity, reduce greenhouse gas emissions, and contribute to mitigating urban heat island effects.

The techno-economic analysis reveals that while both systems are viable, PV1 offers a more attractive return on investment due to its lower initial costs and shorter payback period, despite PV2 producing slightly more electricity. These findings underscore the importance of balancing cost-efficiency with energy production in renewable energy projects.

Beyond economic benefits, the adoption of solar parking canopies aligns with global efforts to transition towards renewable energy and sustainable urban planning. By integrating energy production with urban infrastructure, cities can address growing energy demands, reduce environmental impact, and improve the quality of public spaces.

Furthermore, integrating Internet of Things (IoT) technologies with solar parking systems could amplify their effectiveness. As demonstrated in studies like [9], IoT-enabled parking solutions can improve space utilization, enhance energy efficiency, and provide real-time monitoring and management of parking and energy systems. This integration would enable smarter urban infrastructure, creating opportunities for automated energy management, dynamic charging for electric vehicles, and predictive maintenance for photovoltaic installations.

Future research should explore the long-term performance of such systems under varying climatic conditions, the integration of battery storage for enhanced energy management, and the potential scalability of the approach in different urban settings. Collaboration with policymakers and urban planners is crucial to maximize the adoption and impact of solar parking canopies in creating resilient and energy-efficient cities.

Acknowledgement: *This work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia [grant number 451-03-65/2024-03/200102].*

REFERENCES

[1] A. Mermoud, Figut: Software for the Study and Simulation of Photovoltaic Systems, PVsyst SA (formerly ISE, University of Geneva) - www.pvsyst.com

[2] H. Bybee, J. Durrant, A. McNeel, R. Millsap, R. Vasquez, E. Wiley, Feasibility Study to Install Photo Voltaic Structures at the University of Utah; University of Utah: Salt Lake City, UT, USA, 2010.

[3] Global Solar Atlas, available at https://globalsolaratlas.info/

[4] H. Lohse-Busch, M. Duoba, E. Rask, K. Stutenberg, V. Gowri, L. Slezak, and D. Anderson, Ambient Temperature (20°F, 72°F and 95°F) Impact on Fuel and Energy Consumption for Several Conventional Vehicles, Hybrid and Plug-In Hybrid Electric Vehicles and Battery Electric Vehicle. *SAE Technical Paper 2013-01-1462*, 2013.

[5] L. Erickson, Third report on the installation of shaded parking lot structures with integrated photovoltaic power system at Kansas State University, USA, 2011.

[6] Lj. Stamenić, Solar photovoltaic power in Serbia, Jefferson Institute, Washington, USA, 2009.

[7] T. Tsoutsos, N. Frantzeskaki, V. Gekas, Environmental impacts from the solar energy technologies.

[8] *Energy Policy*, 33(3), 2005, pp 289–96.

[9] V. Masson, M. Bonhomme, J.-L. Salagnac, X. Briottet and A. Lemonsu, Solar panels reduce both global warming and urban heat island. *Frontiers in Environmental Science*, 2(14), 2014, pp 1-10.

[10] B. Bogicević, I. Petović, D. Brkić and J. Pavlović, “Improving Internet of Things Parking Systems,” Facta universitatis, Series: Automatic Control and Robotics vol. 19, no. 3, pp. 163-174, 2020, doi 10.22190/FUACR2003163B.