ISSN 2831-1434

Journal homepage: https://jem.fpm.ues.rs.ba/index.php/journal

Journal of Engineering and Management

Volume 3 / No 1 / February 2025 / 29-34

UDK 620.92:662.997

DOI 10.7251/JEM2501029D

COBISS.RS-ID 142220289

Case study

Solar Potential Assessment: Case Study Findings

Procena potencijala solarne energije: rezultati studija slučaja

L. Djordjević[1*], B. Novaković[1], M. Djurdjev[1], T. Šajnović[2]

[1] University of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin, Serbia
[2] Technical College of Applied Sciences, Zrenjanin, Serbia

Abstract: *This study represents an analysis of solar energy potential through a case study conducted via simulation of a solar power plant. The research focuses on assessing the feasibility and efficiency of solar energy utilization, with particular emphasis on its implications for energy sustainability. The simulation of a 10 MW solar power plant in Vranje, Serbia, serves as the basis for the analysis. Various parameters including solar radiation, energy production, and satisfaction of electricity demands are evaluated across different months. The findings reveal seasonal variations in solar energy production and consumption, with higher satisfaction observed during peak production months. Additionally, the study examines the environmental benefits of solar energy utilization, including reductions in* CO_2 *emissions. The results underscore the significance of integrating renewable energy sources like solar power into the energy mix to achieve sustainability goals. This research contributes to the understanding of solar energy potential and informs decision-making processes towards a more sustainable energy future.*

Keywords: *Solar energy, Case study, Energy Efficiency, Serbia*

Apstrakt*: Ova studija predstavlja analizu potencijala solarne energije kroz studiju slučaja sprovedenu kroz simalaciju solarne elektrane. Istraživanje se fokusira na procenu izvodljivosti i efikasnosti korišćenja solarne energije, sa posebnim osvrtom na implikacije za održivost energije. Simulacija solarnog postrojenja snage 10 MW u Vranju, Srbija, služi kao osnova za analizu. Različiti parametri, uključujući solarno zračenje, proizvodnju energije i zadovoljenje potreba za električnom energijom, procenjuju se tokom različitih meseci. Rezultati otkrivaju sezonske varijacije u proizvodnji i potrošnji energije, sa većim zadovoljavanjem potreba tokom letnjih meseci. Pored toga, studija ispituje ekološke koristi korišćenja solarne energije, uključujući smanjenje emisije* CO_2*. Rezultati naglašavaju značaj integracije obnovljivih izvora energije poput solarne energije u energetski miks kako bi se postigli ciljevi održivosti. Ovo istraživanje doprinosi razumevanju potencijala solarne energije i može da pomogne u procesima donošenja odluka ka održivijoj energetskoj budućnosti.*

Ključne riječi*: Solarna energija, Studija slučaja, Energetska efikasnost, Srbija*

1 INTRODUCTION

In today's world, with increasing challenges in the field of energy and the increasingly evident negative impacts of fossil fuels on the environment, the transition to renewable energy sources becomes imperative [1,2]. One of the most promising renewable energy sources is solar energy, which can be efficiently utilized through solar power plants [3,4]. In this research paper, we focus on analyzing the operation of solar power plants using specialized software tools, with a particular emphasis on the PV syst software.

Globally, in Europe, and in the Balkans, the existence and increasing utilization of renewable energy sources play a crucial role in reducing greenhouse gas emissions and achieving sustainable development goals [5,6]. Europe, as a leader in this process, sets ambitious targets for the share of renewable sources in total energy consumption, which encourages countries to intensify research and implementation of solar power plants [7,8].

The Republic of Serbia, with its abundant natural resources, possesses significant potential for utilizing solar energy. According to available data, the average annual solar radiation in Serbia ranges between 1,400 and 1,600 kWh/m². In the Vojvodina region, the average annual solar radiation is slightly lower, ranging between 1,300 and 1,500 kWh/m² [9,10]. In the southern part of Serbia, including the region around the city of Vranje, the average annual solar radiation is higher, ranging between 1,600 and 1,800 kWh/m². These figures vary depending on the geographical characteristics, altitude, and climatic conditions of each specific region.

However, despite these natural resources, only a small portion of that potential is currently being utilized [11,12].

This paper will explore the possibilities of optimizing the operation of solar power plants in Serbia, using the PV syst software to simulate the operation of solar power plants. The specific focus will be on analyzing the performance of 10 MW solar power plants located in the vicinity of Vranje. Through this analysis, the aim is to identify potential ways to improve efficiency and increase the utilization of solar potential in the region.

Through a combination of technical analysis and economic evaluation, this paper will provide deeper insights into the opportunities and challenges of using solar power plants in Serbia, as well as suggestions for further steps towards a more sustainable energy future.

2 METHODOLOGY

In this study, the simulation of a solar power plant's operation was conducted utilizing PVsyst software [5,13,14], version 7.3. The simulation focused on a solar power plant with a capacity of 10 MWp. This solar facility comprises 25,002 LG 400 N2W-A5 panels and 77 SUN2000-100KTL-M1-400Vac inverters. Detailed specifications of the panels and inverters are provided in *Table 1.*

Table 1. Solar Power Plant Panel and Inverter Specifications

PV module	
Model	LG 400 N2W-A5/Monocrystalline / N-type
Dimensions (L x W x H)	2024 x 1024 x 40 mm
Maximum Power (Pmax)	400
Module Efficiency	19.3
Inverter	
Model	SUN2000-100KTL-M1-400Vac
Operating voltage	200-1000 V
Pnom ratio	1.3

The selection of the simulated solar power plant's location was meticulously undertaken, situated within the industrial zone of the city of Vranje, at coordinates 42.50 N 21.92 E, with an elevation of 446 m, tilt angle of 38 degrees, and azimuth angle of -1 degree. The area occupied by the solar power plant is 51,819 square meters. *Figure 1* illustrates the Photovoltaic Electricity Potential of the Republic of Serbia.

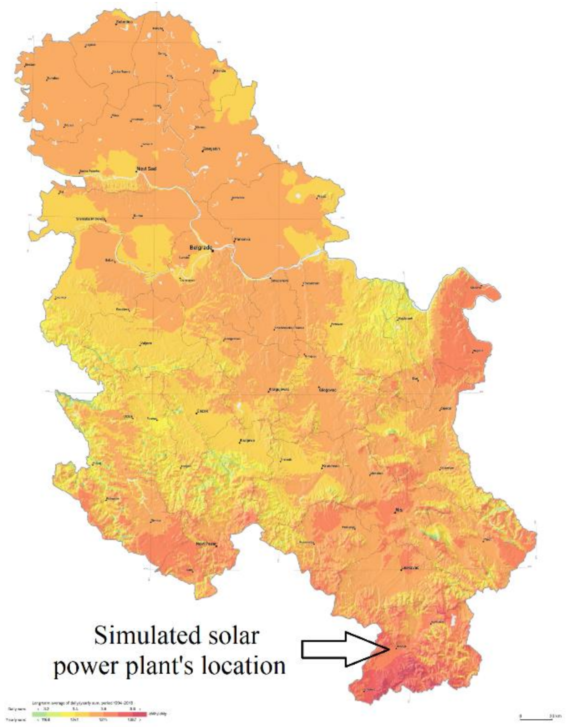

Figure 1 - Photovoltaic Electricity Potential Map of the Republic of Serbia

In addition to the simulation data, sources and documents from relevant institutions of the Republic of Serbia pertaining to this field were utilized for data analysis.

This methodology ensures a comprehensive approach to the investigation, incorporating both technical simulation and data analysis, supported by authoritative sources within the Serbian institutional framework. This methodology ensures a comprehensive approach to the investigation, incorporating both technical simulation and data analysis, supported by authoritative sources within the Serbian institutional framework.

3 RESULTS

Table 2. presents the key findings obtained from the simulation of the solar power plant operation. The table displays results on a monthly basis for ambient average temperature, Global Incident in Coll. Plane, Energy injected into the grid, and Performance Ratio (PR) values. These metrics provide insights into the performance and efficiency of the solar power plant throughout the year, allowing for a comprehensive assessment of its operational characteristics.

Table 2. Simulation Results for Solar Power Plant Operation

Month	Ambient temperature	Global incident in coll. Plane	Energy injected into grid	PR ratio
	°C	kWh/m^2	kWh	%
Jan	-0.18	87.1	793082	91.1
Feb	2.2	112.4	993258	88.4
Mar	7.07	149.3	1270340	85.1
Apr	11.5	149	1256327	84.3
May	16.2	170.7	1410359	82.6
Jun	20.07	179.6	1465959	81.6
Jul	22.89	184.4	1479677	80.2
Aug	23.14	184.3	1481057	80.4
Sep	17.16	155.6	1270740	81.6
Oct	11.94	133.7	1145431	85.7
Nov	6.58	95.3	835301	87.6
Dec	1.32	79.4	712818	89.7
Year	**11.71**	**1680.8**	**14114349**	**84.0**

Figure 2 illustrates the outcomes obtained from the simulation for Normalized Production (per installed kWp). The image depicts metrics such as Collection Loss, System Loss, and Produced Useful Energy (inverter output) on a monthly basis. These data provide valuable insights into the performance efficiency and operational dynamics of the solar power plant throughout the year. Through visual representation, *Figure 2* facilitates a clear understanding of the factors influencing the overall productivity and effectiveness of the solar energy system.

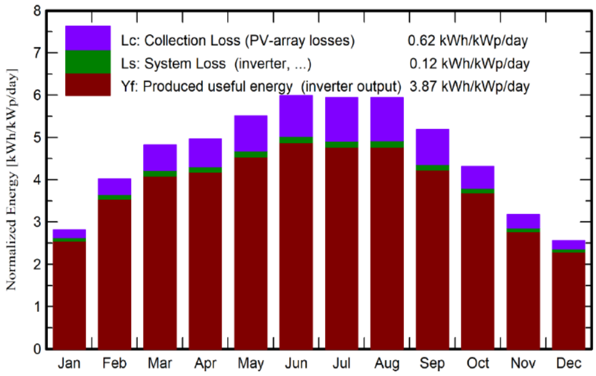

Figure 2 - Normalized Production (per installed kWp)

Table 3. presents the data regarding the amount of electrical energy delivered to the grid obtained from the simulation, both on a monthly basis and the total for the year. Additionally, comparative data on the electricity consumption of the city of Vranje, based on the report of the Electric Distribution Company of Serbia for the year 2022 [15], is provided. This includes the percentage satisfaction of the city's electricity needs by month and the number of households that can be supplied with electricity based on the average household consumption in Serbia for the year 2022, obtained from the annual report of the Electric Power Industry of Serbia [16].

Table 3. Electrical Energy Delivery and Consumption Comparison

Month	Energy injected into grid	Consumption of town of Vranje	% of meeting electricity needs	Number of households according to average electricity needs
	GWh		%	HH
Jan	793.1	55,909	1.42	2360.4
Feb	993.3	46,865	2.12	2956.1
Mar	1270.3	51,663	2.46	3780.8

Apr	1256.3	41,027	3.06	3739.1
May	1410.4	36,251	3.89	4197.5
Jun	1466.0	34,532	4.25	4363.0
Jul	1479.7	37,580	3.94	4403.8
Aug	1481.1	37,261	3.97	4407.9
Sep	1270.7	35,641	3.57	3782.0
Oct	1145.4	41,034	2.79	3409.0
Nov	835.3	43,640	1.91	2486.0
Dec	712.8	50,206	1.42	2121.5
Year	**14,114**	**511,610**	**2.76**	**3500.6**

4 DISCUSSION

The provided dataset presents monthly data for various parameters related to the operation of a solar power plant, including ambient temperature, global incident solar radiation, energy injected into the grid, and Performance Ratio (PR).

4.1 Ambient Temperature:

1. The ambient temperature exhibits a seasonal pattern, with lower values during winter months and higher values during summer months.
2. January records the lowest ambient temperature (-0.18°C), while August registers the highest (23.14°C).
3. The temperatures gradually increase from January to August and then decrease again towards the end of the year.

4.2 Global Incident Solar Radiation:

1. Similar to ambient temperature, global incident solar radiation follows a seasonal trend, peaking in the summer months and declining in winter.
2. The highest global incident solar radiation is observed in July (184.4 kWh/m²), while the lowest is recorded in December (79.4 kWh/m²).
3. The increase in solar radiation during summer months contributes to higher energy generation by the solar power plant.

4.3 Energy Injected into Grid:

1. Energy injected into the grid reflects the actual output of the solar power plant, influenced by both solar radiation and system efficiency.
2. There is a clear seasonal variation in energy production, with higher values during summer months and lower values during winter.
3. The highest energy injection into the grid is recorded in August (1,481,057 kWh), while the lowest is observed in December (712,818 kWh).

4.4 Performance Ratio (PR):

1. PR is a measure of the efficiency of the solar power plant, representing the ratio of actual energy output to the theoretically maximum possible output.
2. The PR values range from 80.2% to 91.1%, indicating a relatively high level of efficiency throughout the year.
3. The lowest PR is observed in July (80.2%), possibly due to higher ambient temperatures leading to reduced system efficiency.
4. Conversely, the highest PR is recorded in January (91.1%), suggesting optimal system performance during colder months.

The data presented in Figure 2 depict metrics related to Collection Loss, System Loss, and Produced Useful Energy (inverter output).

4.5 Collection Loss:

The average Collection Loss amounts to 0.62 kWh/kWp/day, with noticeably higher values during summer months. This trend is primarily attributed to the significant impact of increased temperatures on the efficiency of solar panels, as evidenced by the higher PR values observed during the summer period with elevated ambient temperatures. Collection Loss represents the energy that is not captured by the solar panels due to various factors such as shading, soiling, and mismatch losses. The increase in temperature exacerbates these losses, leading to higher Collection Loss values during warmer months.

4.6 System Loss:

The average System Loss is recorded at 0.12 kWh/kWp/day, with minor deviations throughout the year (slightly higher losses during warmer months), but without significantly large spikes in losses as observed in Collection Loss. System Loss encompasses losses within the entire solar power system, including losses in wiring, inverters, and other components. The relatively consistent values indicate stable system performance with minor fluctuations associated with seasonal variations in temperature.

4.7 Produced Useful Energy (Inverter Output):

The average Produced Useful Energy amounts to 3.87 kWh/kWp/day, with production increases following the trend of radiation quantity/variation throughout the year. Produced Useful Energy represents the actual energy output of the solar power plant after accounting for losses. The increase in production aligns with the trend of radiation variation throughout the year, with higher production during months with greater solar radiation.

Based on the data presented in Table 3., the following observations can be made:

The highest satisfaction of the city of Vranje's electricity needs through the solar power plant occurred in June, with a percentage of 4.25%, while the lowest satisfaction was recorded in January and December, both with percentages of 1.42%. On average, the satisfaction of electricity needs throughout the year amounted to 2.76%. These findings indicate a seasonal variation in both electricity production and consumption, with higher satisfaction during the summer months when solar production peaks.

Further analysis reveals that the number of households supplied with solar energy varies across months. June shows the highest potential, with 4363.0 households, whereas December demonstrates the lowest potential, with 2121.5 households. This underscores the seasonal fluctuation in the availability of solar energy for household consumption.

The data suggests that while solar energy contributes significantly to meeting Vranje's electricity demands, especially during peak production months, it is not sufficient to fully cover the city's needs year-round. However, the variability in satisfaction percentages and the number of households supplied highlight the potential for decentralized energy generation and its role in augmenting energy independence. This underscores the importance of adopting comprehensive energy strategies that integrate renewable sources like solar energy with conventional energy sources to ensure a resilient and sustainable energy future for Vranje and beyond.

5 CONCLUSIONS

In conclusion, this study provides valuable insights into the potential of solar energy in meeting electricity demands, as well as its implications for the city of Vranje and Serbia as a whole.

The annual production of the 10 MW solar power plant was found to be 14,114.3 GWh, contributing to the city's electricity needs. On average, the solar power plant satisfied approximately 2.76% of Vranje's electricity needs, with varying levels of satisfaction across different months. The number of households supplied with solar energy ranged from 2121.5 to 4363.0, reflecting seasonal fluctuations in solar energy availability.

Additionally, the analysis revealed a high average Performance Ratio (PR) for the solar power plant, indicative of its efficient operation. Such high PR values are consistent with those observed in most European countries, highlighting the effectiveness of solar energy utilization in various regions.

Furthermore, it is crucial to note that Serbia predominantly relies on coal-fired power plants for electricity generation. Considering the consumption of 1 kg of coal to produce 1 kWh of electricity, the annual operation of the solar power plant would save approximately 14,114 tons of coal and reduce CO_2 emissions by 40,367 tons. This underscores the potential environmental benefits of transitioning towards renewable energy sources like solar power.

Overall, this research underscores the importance of further developing solar energy infrastructure in Serbia. Such endeavors are crucial for enhancing energy security, reducing greenhouse gas emissions, and fostering sustainable development. As Serbia strives towards a greener and more resilient energy future, studies like this play a vital role in informing policy decisions and driving progress in the renewable energy sector.

Acknowledgment

This research was conducted through the project "Creating laboratory conditions for research, development, and education in the field of the use of solar resources in the Internet of Things" at the Technical Faculty, Mihajlo Pupin, Zrenjanin, financed by the Provincial Secretariat for Higher Education and Scientific Research, Republic of Serbia, Autonomous Province of Vojvodina, Project number 142-451- 3487/2023-01/01.

6 REFERENCES

[1] Ebhota, W. S., & Jen, T.-C. (2020). Fossil Fuels Environmental Challenges and the Role of Solar Photovoltaic Technology Advances in Fast Tracking Hybrid Renewable Energy System. *International Journal of Precision Engineering and Manufacturing-Green Technology*, *7*(1), 97–117. https://doi.org/10.1007/s40684-019-00101-9

[2] Yi, S., Raza Abbasi, K., Hussain, K., Albaker, A., & Alvarado, R. (2023). Environmental concerns in the United States: Can renewable energy, fossil fuel energy, and natural resources depletion help? *Gondwana Research*, *117*, 41–55. https://doi.org/10.1016/j.gr.2022.12.021

[3] Colak, H. E., Memisoglu, T., & Gercek, Y. (2020). Optimal site selection for solar photovoltaic (PV) power plants using GIS and AHP: A case study of Malatya Province, Turkey. *Renewable Energy*, *149*, 565–576. https://doi.org/10.1016/j.renene.2019.12.078

[4] Hosseini, S. E., & Wahid, M. A. (2020). Hydrogen from solar energy, a clean energy carrier from a sustainable source of energy. *International Journal of Energy Research*, *44*(6), 4110–4131. https://doi.org/10.1002/er.4930

[5] Djordjević, L., Pekez, J., Novaković, B., Bakator, M., Djurdjev, M., Ćoćkalo, D., & Jovanović, S. (2023). Increasing Energy Efficiency of Buildings in Serbia—A Case of an Urban Neighborhood. *Sustainability*, *15*(7), 6300. https://doi.org/10.3390/su15076300

[6] Pejović, B., Karadžić, V., Dragašević, Z., & Backović, T. (2021). Economic growth, energy consumption and CO2 emissions in the countries of the European Union and the Western Balkans. *Energy Reports*, *7*, 2775–2783. https://doi.org/10.1016/j.egyr.2021.05.011

[7] Musiał, W., Zioło, M., Luty, L., & Musiał, K. (2021). Energy Policy of European Union Member States in the Context of Renewable Energy Sources Development. *Energies*, *14*(10), 2864. https://doi.org/10.3390/en14102864

[8] Puertas, R., & Marti, L. (2022). Renewable energy production capacity and consumption in Europe. *Science of The Total Environment*, *853*, 158592. https://doi.org/10.1016/j.scitotenv.2022.158592

[9] Djordjevic, L., Prvulovic, S., Djurdjev, M., Novakovic, B., & Bakator, M. (2024). SOLAR TECHNOLOGY: EMPOWERING SERBIA'S RENEWABLE ENERGY FUTURE. *Materiali in Tehnologije*, *58*(1). https://doi.org/10.17222/mit.2023.944

[10] Prvulovic, S., Tolmac, D., Matic, M., Radovanovic, L., & Lambic, M. (2018). Some aspects of the use of solar energy in Serbia. *Energy Sources, Part B: Economics, Planning, and Policy*, *13*(4), 237–245. https://doi.org/10.1080/15567249.2012.714842

[11] Bajc, T., & Kostadinović, D. (2023). Potential of usage of the floating photovoltaic systems on natural and artificial lakes in the Republic of Serbia. *Journal of Cleaner Production*, *422*, 138598. https://doi.org/10.1016/j.jclepro.2023.138598

[12] Pavlović, T., Milosavljević, D., Radonjić, I., Pantić, L., Radivojević, A., & Pavlović, M. (2013). Possibility of electricity generation using PV solar plants in Serbia. *Renewable and Sustainable Energy Reviews*, *20*, 201–218. https://doi.org/10.1016/j.rser.2012.11.070

[13] Baqir, M., & Channi, H. K. (2022). Analysis and design of solar PV system using Pvsyst software. *Materials Today: Proceedings*, *48*, 1332–1338. https://doi.org/10.1016/j.matpr.2021.09.029

[14] Kumar, R., Rajoria, C. S., Sharma, A., & Suhag, S. (2021). Design and simulation of standalone solar PV system using PVsyst Software: A case study. *Materials Today: Proceedings*, *46*, 5322–5328. https://doi.org/10.1016/j.matpr.2020.08.785

[15] Serbian Public Electric Utility Company. (2023). *Energy data 2022*. https://elektrodistribucija.rs/

[16] Electricity Power indusrty of Serbia. (2023). *Technical report 2022*. https://www.eps.rs/eng/Pages/Technical-reports.aspx