JOURNAL OF PRODUCTION ENGINEERING VOL. 28, NO. 2 (2025)
DOI: 10.24867/JPE-2025-02-010

Original research article

Journal of
Production Engineering

https://jpe.ftn.uns.ac.rs/index.php/jpe
ISSN: 1821-4932 (print), ISSN: 2956-2252 (online)

Efficiency Evaluation of a Photovoltaic System at the Technical Faculty "Mihajlo Pupin" Zrenjanin

Luka Djordjević,[a] 0000-0003-4578-9060, **Borivoj Novaković,**[a*] 0000-0003-2816-3584

Mihalj Bakator,[a] 0000-0001-8540-2460, **Stefan Ugrinov,**[a] 0009-0001-1680-6557, **Milan Nikolić**[a] 0000-0001-6643-1442, **Stevica Jankov**[b] 0009-0000-6503-8200

[a] Technical Faculty "Mihajlio Pupin" Zrenjanin, University of Novi Sad, Serbia
[b] NAFTAGAS – Oil Services LLC, Novi Sad, Serbia

ABSTRACT

Solar energy represents a cornerstone of sustainable development, offering a clean and renewable solution to meet growing energy demands while reducing environmental impact. This study evaluates the performance of a 60.9 kWp photovoltaic (PV) system installed at the Technical Faculty "Mihajlo Pupin" in Zrenjanin, Serbia, over the first six months of 2025. The system, comprising 106 monocrystalline modules and a 50kW inverter, was commissioned on January 16, 2025, and integrated into the national grid as a prosumer in April 2025. Monthly data on energy production, consumption, and environmental metrics were collected using a monitoring platform and an on-site meteorological station, capturing global horizontal irradiation, temperature, and sun hours. The analysis focuses on energy efficiency, economic savings, and environmental benefits, with particular attention to the impact of increased solar irradiation and the prosumer framework. These findings provide insights into the system's contribution to institutional sustainability and its potential as a model for renewable energy adoption in Serbia.

ARTICLE INFO

Received: 11 July 2025
Revised: 3 September 2025
Accepted: 30 September 2025

KEYWORDS:
PV system;
Renewable energy;
Prosumer;
Energy efficiency;
CO_2 reduction.

**Corresponding author's.e-mail: borivoj.novakovic@uns.ac.rs*

1. INTRODUCTION

Solar energy has emerged as a cornerstone of the global transition toward sustainable energy systems, addressing pressing challenges related to climate change, energy security, and the reduction of greenhouse gas emissions [1]. According to the International Renewable Energy Agency (IRENA), global photovoltaic (PV) capacity surpassed 1,865 GW in 2024, with significant contributions from countries such as China, India, and members of the European Union [2]. Solar systems provide a technologically robust and economically viable solution for generating clean electricity, reducing dependence on fossil fuels, lowering energy costs, and fostering local economic development through job creation [3], [4]. Moreover, solar energy plays a critical role in achieving the objectives of the Paris Agreement, which aims to limit global temperature rise to 1.5°C above pre-industrial levels [5].

In Europe, the adoption of PV systems has accelerated, driven by European Union policies targeting decarbonization and an increase in the share of renewable energy to 42.5 % by 2030, as outlined in the revised Renewable Energy Directive (RED III) [6]. Countries such as Germany, Spain, and Italy lead in installed solar capacity, while smaller nations, including Serbia, are increasingly recognizing the potential of solar energy [7], [8]. In Serbia, the development of solar systems is gaining momentum through supportive regulatory frameworks, including incentives for prosumers (producer-consumers) and the integration of renewable energy into the national grid. Serbia's National Renewable Energy Strategy sets a target of achieving a 40 % share of renewable energy by 2040, [9] with PV systems playing a pivotal role, particularly in reducing reliance on coal, which continues to dominate the country's energy sector [10]. Despite global and regional progress, the deployment of solar systems faces challenges, including seasonal variability in

Published by the University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia.

solar irradiation, the need for efficient energy storage solutions, and integration into existing power grids. These challenges are particularly pronounced in countries like Serbia, where climatic conditions range from cold winters with limited solar irradiation to warm summers with abundant sunshine [11]. Consequently, evaluating the performance of solar systems under local conditions is essential for optimizing their efficiency, economic viability, and contribution to sustainability. This study examines the performance of a 60.9 kWp PV system installed at the Technical Faculty "Mihajlo Pupin" in Zrenjanin, Serbia, over a six-month period from January to June 2025. The system, comprising 106 monocrystalline PV modules and a high-efficiency Huawei M3 inverter, was designed to meet stringent international standards and local safety requirements. The analysis focuses on key performance metrics, including energy yield, grid interaction, self-consumption, economic savings, and environmental benefits. By assessing monthly data on PV yield, energy balance, electricity costs, and environmental impacts such as CO_2 avoidance and coal savings, this study provides insights into the system's operational effectiveness and its alignment with Serbia's renewable energy goals. The findings aim to inform strategies for improving solar system performance, particularly in addressing seasonal variability and self-consumption during low-yield periods, while contributing to the broader discourse on sustainable energy solutions in Serbia and beyond.

2. MATERIALS AND METHODS

The PV power system analyzed in this study is situated on the premises of the Technical Faculty "Mihajlo Pupin" in Zrenjanin, Serbia. The installation comprises 106 monocrystalline PV module, Table 1, with a combined nominal power of 60.9 kWp. The modules conform to IEC 61215 and IEC 61730 standards, ensuring mechanical robustness, electrical safety, and long-term operational stability under regional climatic conditions. Each panel is mounted on corrosion-resistant support structures designed for local wind and snow loads, and connected to a certified grounding system for fault protection.

Table 1 - *PV module specification.*

Model	Trinasolar, Vertex TSM-DE19R
Module type	Monocrystalline/N-type
Maximum Power (Pmax)	575 W
No. of cells	132
Power Tolerance	0 ~ +5
MPP Voltage (Vmpp)	38.8 V
Open Circuit Voltage (Voc)	46.1 V
MPP Current (Impp)	14.83 A
Short Circuit Current (Isc)	15.9 A
Efficiency	21.6 %
Units	106

The direct current generated by the PV array is converted to alternating current via a Huawei SUN2000-50KTL-M3 inverter rated at 50 kW, Table 2. The inverter achieves a conversion efficiency exceeding 98 % and is equipped with advanced monitoring capabilities through standard industrial communication protocols.

Table 2 - *Inverter specification.*

Model	Huawei, SUN2000-50KTL-M3
MPPT voltage range	200 – 1000Vdc
Rated output power	50 kW
Max. Output power	55 kW
Max. output current	84.0A/380Vac 79.8A/400Vac 66.5A/480Vac
Nominal output frequency	50/60Hz
Max. Efficiency	98.5 %

Protection and switching components are housed within a custom-built distribution cabinet, which includes surge protection devices, circuit breakers, and system isolation mechanisms compliant with national and international safety standards.

Energy output, grid exchange, and consumption data were recorded on a monthly basis for the period between January and June 2025. Environmental parameters including global horizontal irradiation, temperature, wind conditions, and solar hours were continuously logged by a local meteorological station installed on-site.

Functional testing of all components, including grounding resistance, insulation integrity, and protective relay behavior, was conducted prior to commissioning in accordance with SRPS ISO/IEC 17020:2012. The system became operational on January 16, 2025, following approval from relevant inspection authorities.

For analytical purposes, monthly performance data such as theoretical yield, actual PV yield, inverter output, export to grid, import from grid, self-consumption, CO2 displacement, and standard coal savings were obtained directly from the monitoring platform. From April 2025 onward, the facility was officially registered as a prosumer under the national energy regulatory framework, with surplus energy exported to the grid receiving financial credit. Prior to April, utility billing was based solely on imported energy, without offset for on-site generation.

Quantitative performance metrics were analyzed for the six-month operational window, focusing on indicators relevant to energy efficiency, economic savings, and environmental impact. Particular emphasis was placed on the transition point in April 2025, when the billing structure changed due to prosumer registration, allowing comparative evaluation of pre- and post-integration scenarios.

3. POWER PLANT PERFORMANCE RESULTS

Table 3 presents the monthly performance metrics, including global irradiation, sun hours, average temperature, PV yield, inverter yield, and peak power.

The photovoltaic system at the Technical Faculty “Mihajlo Pupin” in Zrenjanin, Serbia, demonstrated strong performance from January to June 2025, with PV yield rising from 1001.96 kWh to 11331.35 kWh, driven by increased global irradiation (21.17 to 76.43 kWh/m2) and sun hours (63.25 to 376.58 h). The inverter’s 98.5 % efficiency ensured negligible conversion losses, and peak power reached 55 kW from March onward.

Table 4 summarizes the energy balance, including export to the grid, import from the grid, consumption, self-consumption, and self-consumption rate

Table 3 - *Monthly Performance Metrics.*

Month	Global Irradiation	Sun Hours	Avg. Temp.	PV Yield	Inverter Yield	Peak Power
	(kWh/m^2)	(h)	(°C)	(kWh)	(kWh)	(kW)
January	21.17	63.25	4.82	1001.96	1001.96	32.36
February	69.16	191.92	2.37	3459.17	3459.17	40.52
March	77.71	229.08	10.62	5221.91	5221.91	55.00
April	79.94	298.67	14.47	8076.73	8076.73	55.00
May	69.56	342.58	16.56	9229.39	9229.39	55.00
June	76.43	376.58	25.79	11331.35	11331.35	55.00

Table 4 - *Energy Balance Metrics.*

Month	Export	Import	Consumption	Self-Consumption	Self-Consumption Rate
	(kWh)	(kWh)	(kWh)	(kWh)	(%)
January	216.01	3711.61	4,497.56	785.95	78.44
February	1257.32	5197.72	7,399.57	2201.85	63.65
March	2574.49	5248.78	7,896.20	2647.42	50.70
April	4776.45	4093.78	7,394.06	3300.28	40.86
May	6199.49	3316.23	6,346.13	3029.90	32.83
June	7226.56	3760.67	7,865.46	4104.79	36.23

The photovoltaic system at the Technical Faculty “Mihajlo Pupin” in Zrenjanin, Serbia, demonstrated strong performance from January to June 2025, with PV yield rising from 1001.96 kWh to 11331.35 kWh, driven by increased global irradiation (21.17 to 76.43 kWh/m2) and sun hours (63.25 to 376.58 h). The inverter’s 98.5 % efficiency ensured negligible conversion losses, and peak power reached 55 kW from March onward.

Before April 2025 self-consumption rates were higher (50.70 - 78.44 %), with export 216.01 - 2574.49 kWh and significant import 3711.61 - 5248.78 kWh. After April, export increased (4776.45 - 7226.56 kWh), import decreased (3316.23 - 4093.78 kWh), and self-consumption rates dropped (32.83 - 40.86 %). Figure 1 graphically depicts the energy balance shown in Table 4.

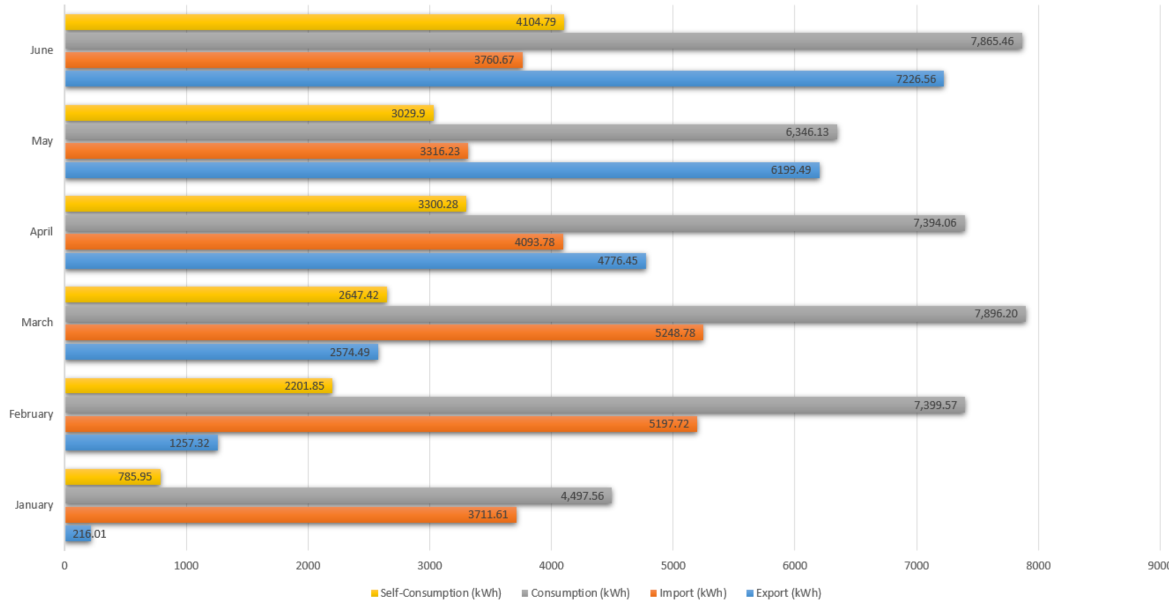

Fig. 1 *Energy Balance.*

Table 5 compares monthly electricity bills in 2025 with the average bills for the same months over the previous twoyears and quantifies environmental benefits Electricity bills decreased significantly after April, from €1787.79 in January to €602.22 in June, yielding total savings of approximately €3400. CO_2 avoidance increased from 0.48 t in January to 5.38 t in June (total 18.20 t), and standard coal savings rose from 0.40 t to 4.53 t (total 15.34 t). Figure 2 graphically displays the economic and environmental data shown in Table 5.

Table 5 - *Economic and Environmental Metrics.*

Month	Electricity Bill 2025	Avg. Bill (Prev. 2 Years)	CO_2 Avoided	Standard Coal Saved
	(€)	(€)	(kg)	(kg)
January	1787.79	1382.80	480	400
February	1259.34	1363.33	1640	1380
March	1287.93	1526.40	2480	2090
April	644.19	1455.38	3840	3230
May	628.87	1391.76	4380	3690
June	602.22	1456.82	5380	4530
Sum	6210.34	8576.49	18200	15320

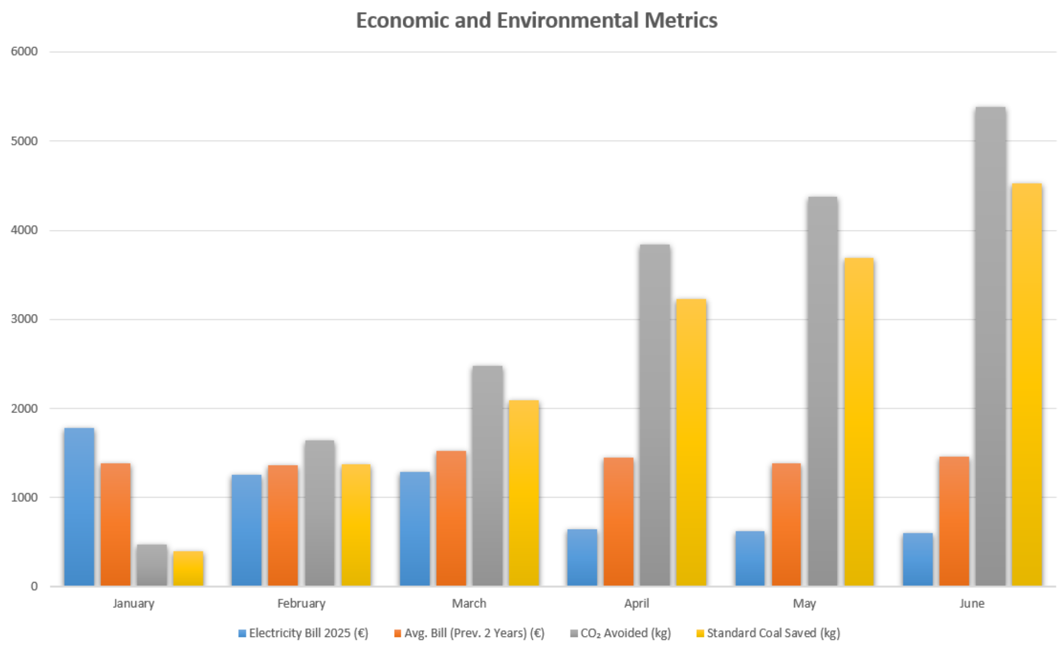

Fig. 2 *Economic and Environmental Metrics.*

4. Discussion

The PV system's performance data from January to June 2025 as shown in Tables 3-5 and Figures 1-2, demonstrate notable system responsiveness with a pronounced shift in energy performance in April 2025. There was a progressive rise in PV yield from 1001.96 kWh in January to 11331.35 kWh in June, accompanied by an increase in global irradiation (21.17 to 76.43 kWh/m2) and sun hours (63.25 to 376.58 h). This suggests that solar energy during the summer months was as dependable in Serbia as was anticipated. The inverter's consistent equivalence between PV and inverter yields across all months underscores its high efficiency, indicating minimal energy losses during conversion. The peak power output stabilized at 55 kW from March onward.

The energy balance metrics (Table 4, Figure 1) demonstrate the influence of increased solar irradiation on the photovoltaic system's performance. From January to March, self-consumption rates were high (50.70 - 78.44 %), with substantial grid imports (3711.61 - 5248.78 kWh) and modest exports (216.01 - 2574.49 kWh), reflecting lower solar yields in winter months. From April to June, higher irradiation and extended sun hours boosted PV production, leading to increased exports (4776.45 - 7226.56kWh), reduced imports (3316.23 - 4093.78 kWh), and lower self-consumption rates (32.83 - 40.86 %). The economic benefits (Table 5, Figure 2) were substantial, with electricity bills dropping from €1787.79 in January to €602.22 in June, yielding approximately €3400 in savings compared to the previous two years' averages (€1382.80 - €1526.40). The most significant reductions occurred in April - June, driven by the prosumer framework's financial credits for exported energy.

Environmentally, the system contributed significantly to sustainability, avoiding 18.20 t of CO2 and saving 15.32 t of standard coal over the six months (Table 5, Figure 2). The increase from 0.48 t CO_2 avoided in January to 5.38 t in June correlates with higher PV yields, demonstrating the system's growing environmental impact as solar conditions improved. These savings align with Serbia's renewable energy objectives, reducing the faculty's carbon footprint and reliance on fossil fuels. The economic and environmental benefits underscore the value of prosumer integration, but the high import levels in January–March indicate a need for strategies to balance self-consumption and exports in low-yield months, possibly through energy storage solutions.

5. CONCLUSION

The photovoltaic (PV) system at the Technical Faculty "Mihajlo Pupin" in Zrenjanin, Serbia, demonstrated significant benefits during its operation from January to June 2025. The system, with a capacity of 60.9 kWp, achieved a substantial increase in energy production, from 1001.96 kWh in January to 11331.35 kWh in June, driven by rising global irradiation (21.17 to 76.43 kWh/m2) and sun hours (63.25 to 376.58 h). This led to a marked reduction in electricity bills, dropping from €1787.79 in January to €602.22 in June, yielding approximately €3400 in savings compared to historical averages. The environmental impact was equally notable, with 18.20 t of CO2 avoided and 15.34 t of standard coal saved, contributing to a reduced carbon footprint and supporting Serbia's sustainability goals. The high efficiency of the inverter (98.5%) ensured minimal energy losses, while the system's reliability, validated by SRPS ISO/IEC 17020:2012 standards, underscores its suitability for both operational and educational purposes. The shift in energy balance after April 2025, with increased exports (4776.45 - 7226.56 kWh) and reduced imports (3316.23 - 4093.78 kWh) due to higher solar yields, highlights the system's ability to meet stable demand (6346.13 - 7896.20 kWh) with on-site generation. Future studies should investigate the impact of seasonal weather variability, potential energy storage solutions to optimize self-consumption in low-yield months, and refinements to theoretical yield models to better predict performance under local conditions, further enhancing the system's economic and environmental contributions.

REFERENCES

[1] Sreekanth, K. J. (2024). Energy Policy Analyses, Energy Transition and Sustainability. In *Energy Efficiency Improvements with Emission Abatement for Energy Sustainability* (K. J. Sreekanth, Ed.), Springer Nature Singapore, Singapore, pp. 135–167. https://doi.org/10.1007/978-981-97-9480-5_8

[2] IRENA. (2025). *Renewable Capacity Statistics 2025*. Accessed July 22, 2025. Available online: https://www.irena.org/Publications/2025/Mar/Renewable-capacity-statistics-2025

[3] Agbakwuru, V., Obidi, P. O., Salihu, O. S., & MaryJane, O. C. (2024). The role of renewable energy in achieving sustainable development goals. *International Journal of Engineering Research Updates*, 7(2): 013–027. https://doi.org/10.53430/ijeru.2024.7.2.0046

[4] Đorđević, L., Bakator, M., Novaković, B., & Đurđev, M. (2024). Building Competitiveness in Industry 5.0: The Role of AI in Improving Production Efficiency. In *New Technologies, Development and Application VII* (I. Karabegović, A. Kovačević, & S. Mandžuka, Eds.), Lecture Notes in Networks and Systems, Vol. 1069, Springer Nature Switzerland, Cham, pp. 435–442. https://doi.org/10.1007/978-3-031-66268-3_44

[5] Matthews, H. D., & Wynes, S. (2022). Current global efforts are insufficient to limit warming to 1.5°C. *Science*, 376(6600): 1404–1409. https://doi.org/10.1126/science.abo3378

[6] Montel, T. (2025). *What is the EU's Renewable Energy Directive?* Accessed July 23, 2025. Available online: https://montel.energy/resources/blog/what-is-the-eus-renewable-energy-directive

[7] Marolin, M., Drvenkar, N., & Unukić, I. (2020). The potential of solar energy as a driver of regional development – challenges and opportunities. *International Journal of Energy Economics and Policy*, 10(6): 411–420. https://doi.org/10.32479/ijeep.10068

[8] Apeh, O. O., Meyer, E. L., & Overen, O. K. (2022). Contributions of solar photovoltaic systems to environmental and socioeconomic aspects of national development—A review. *Energies*, 15(16): 5963. https://doi.org/10.3390/en15165963

[9] Method, E. (2025). *Serbia's goal of 40% renewable energy by 2040: A bright future for clean energy.* Accessed July 23, 2025. Available online: https://www.methodenergy.co/serbias-goal-of-40-renewable-energy-by-2040-a-bright-future-for-clean-energy/

[10] Ćetković, S. (2022). Energy Governance in Serbia. In *Handbook of Energy Governance in Europe* (M. Knodt & J. Kemmerzell, Eds.), Springer International Publishing, Cham, pp. 1037–1053. https://doi.org/10.1007/978-3-030-43250-8_26

[11] Djordjević, L., et al. (2023). Increasing energy efficiency of buildings in Serbia—A case of an urban neighborhood. *Sustainability*, 15(7): 6300. https://doi.org/10.3390/su15076300