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COMPARATIVE ANALYSIS OF RESIDENTIAL PHOTOVOLTAIC SYSTEMS: IMPACT OF SHADING AND ORIENTATION ON ENERGY PRODUCTION

Anca-Adriana Petcut-Lasc[1,2], Valentina-Emilia Balas[1,3], Flavius-Maxim Petcut[1]
[1]Aurel Vlaicu University of Arad, Romania
[2]Petroleum-Gas University of Ploiesti, Romania
[3]Academy of Romanian Scientists, Bucharest, Romania
e-mail: anca.petcut@uav.ro

Abstract: Residential photovoltaic (PV) systems represent a growing trend in sustainable energy generation. Their efficiency is significantly influenced by installation parameters such as orientation, tilt angle, and shading. This paper conducts a comparative study of two PV systems under similar residential conditions: one with an optimal south-facing orientation, and a second that is partially shaded and primarily west-facing. The energy production of both systems is analyzed over a representative period. This analysis reveals the production losses attributed to shading and suboptimal orientation. Results demonstrate significant disparities in energy yield and efficiency, which underscores the necessity of proper system design for achieving long-term financial viability and energy independence. The findings of this study provide a better understanding of the practical challenges encountered in residential PV deployment, informing decisions related to system sizing and placement.
Key words: PV, grid, photovoltaic systems, energy efficiency, residential applications, shading losses, panel orientation

INTRODUCTION

The global transition towards renewable energy sources has placed photovoltaic (PV) systems at the forefront of sustainable energy generation. In particular, residential PV installations have gained significant attention due to their ability to provide clean energy, reduce household electricity costs, and contribute to decarbonization targets. Within the European context, initiatives such as the European Green Deal emphasize the strategic role of solar energy in achieving climate neutrality by 2050. Similar policies and incentives worldwide continue to drive the adoption of residential PV systems as an accessible and effective solution for both individual households and the broader energy grid [1], [2].
Despite these advantages, the performance of PV systems is highly dependent on environmental and installation-related factors. Among the most critical parameters influencing energy yield are the orientation, tilt angle, and the presence of shading. While optimally oriented PV systems can operate close to their rated efficiency, residential installations often face limitations such as roof geometry, architectural constraints, or surrounding obstacles (trees, neighboring buildings), which result in suboptimal placement. These conditions can lead to reduced energy production, mismatch losses, and lower overall efficiency, undermining the financial and environmental benefits of the system [3], [4].
The aim of this paper is to provide a comparative analysis of two residential PV systems installed under different conditions: one with optimal orientation towards the south and minimal shading, and another partially shaded and oriented towards the west. By examining the energy production of both systems over a defined period, the study highlights the quantitative impact of shading and misalignment on electricity generation. The results emphasize the importance of proper design and installation in residential applications, offering practical insights for homeowners, installers, and policymakers. Furthermore, the findings underline the necessity of considering advanced technologies such as micro-inverters and power optimizers to mitigate shading effects and improve system performance [5], [6].

METHODOLOGY

Description of the Analyzed Systems

For this study, two residential photovoltaic (PV) systems installed under different conditions were selected in order to evaluate the impact of orientation and shading on energy production. Both systems are located in the same geographical region to ensure comparable climatic conditions, but differ in installation geometry and exposure to shading.

- System 1 (Optimally Oriented): Installed with a south-facing orientation and a tilt angle close to the site's latitude, ensuring maximum annual irradiance capture. This system has minimal shading throughout the day.
- System 2 (Shaded and West-Facing): Installed with a west-facing orientation, with modules receiving direct sunlight predominantly in the afternoon. The system is partially affected by shading from nearby obstacles, leading to significant mismatch losses.

Both systems utilize monocrystalline silicon PV modules of same nominal 5.2 KW capacity to allow for direct comparison. The installed power, number of modules, and inverter specifications are the same [7].

Site Location and Climatic Conditions

The analyzed residential photovoltaic installations are situated in Socodor, Arad, Romania, a region characterized by a temperate-continental climate. The average annual solar irradiation based on Global Solar Atlas (World Bank/ESMAP, Solargis) is approximately 1,300 kWh/m², which provides favorable conditions for solar energy generation. Climatic data, including solar irradiance and ambient temperature, were obtained from the nearest meteorological station to validate the environmental parameters during the monitoring period. Since all installations are located within the same geographical area, the influence of environmental variability is minimized, ensuring that observed performance differences can be primarily attributed to panel orientation and shading effects rather than climatic disparities [8].

Equipment Specifications

PV Modules: Both systems are equipped with 12 monocrystalline PV panels rated at 425 W/module, chosen for their high efficiency and suitability in residential applications.
Inverters: Each system employs a grid-connected inverter, with maximum efficiency above 97%. The inverter for System 1 is equipped with dual MPPT trackers, while System 2 utilizes a similar inverter but without optimizers.
Mounting Structures: Aluminum-based mounting frames adapted to the roof geometry of each residence [9].

Data Acquisition and Monitoring

Energy production data were collected over a period of one month (September 2024), using integrated inverter monitoring platforms and a smart meter installed at each site. The monitored parameters include: Daily energy yield (kWh), Power injected into the grid (kWh), Self-consumption from PV (kWh), Energy imported from the grid (kWh).
This approach provides sufficient temporal resolution for comparative analysis of orientation/shading impacts while relying on well-established PV monitoring practices. Data treatment considered known behaviors of PV arrays under partial shading (multiple MPPs, power oscillations) and temperature-dependent performance, as reported in modelling and diagnostic studies [10], [11], [12], [13]. The chosen indicators are standard for residential PV performance assessment and fault/underperformance screening [4], [13].

RESULTS AND DISCUSSION

Energy Yield Comparison

The monitored data show a significant difference in the energy production between the optimally oriented PV system (System 1) and the west-facing, partially shaded system (System 2). Table 1 summarizes the daily yields for a representative 10-day period in September.

Table 1. *Comparative daily yields for the two PV systems (4-15 July 2025)*

Day	Date	System 1 – South-facing (kWh)	System 2 – West-facing & shaded (kWh)	Difference (%)
1	4 July 2025	34.05	22.53	-33.83%
2	5 July 2025	35.12	24.72	-29.61%
3	6 July 2025	33.02	22.57	-31.65%
4	7 July 2025	29.03	15.48	-46.68%
5	8 July 2025	22.71	10.54	-53.59%
6	9 July 2025	7.21	5.42	-24.83%
7	10 July 2025	16.33	13.11	-19.72%
8	11 July 2025	18.56	13.27	-28.50%
9	12 July 2025	24.81	16.18	-34.78%
10	13 July 2025	28.78	20.36	-29.26%

The results indicate that System 2 consistently produced 30–35% less energy than System 1, with losses difference being less pronounced on partially cloudy days (Days 6–8), when shading affected also the well faced system making it to work closer to a shaded system.

Economic Implications

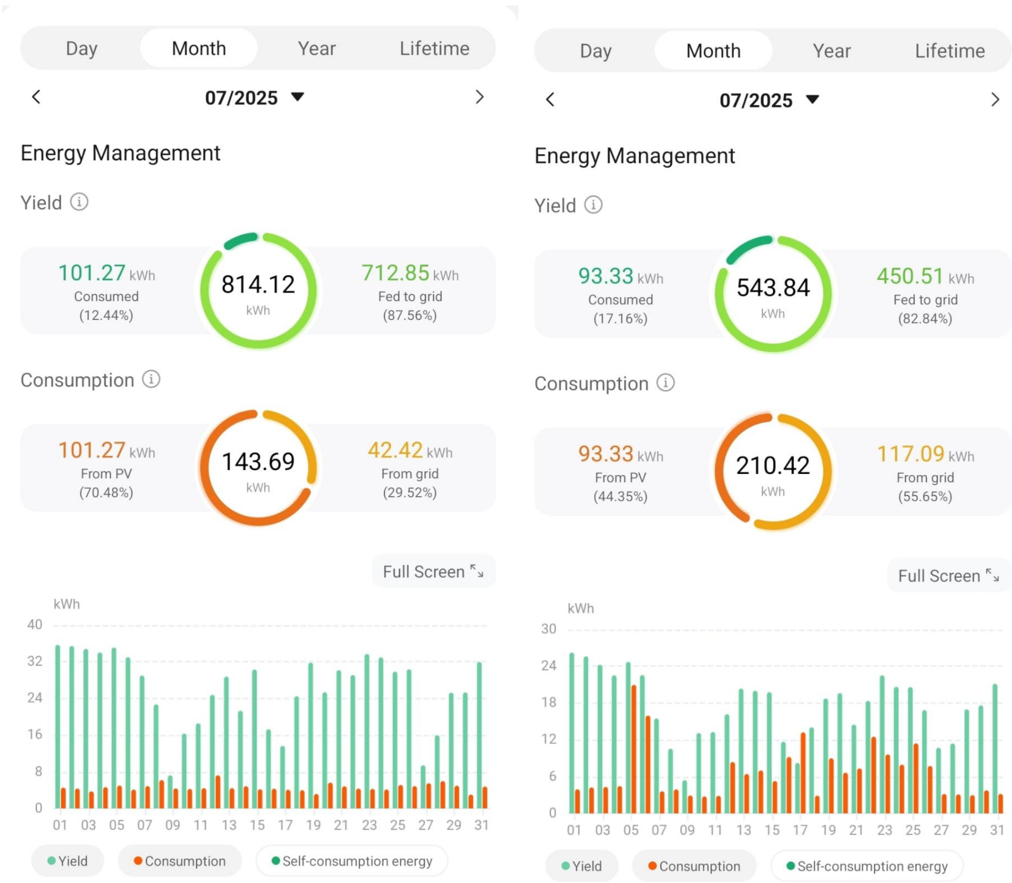

Fig. 1. *System 1 (on left) and System 2 (on right) production and consumption in July 2025*

Based on Fig. 1 and assuming an average residential electricity price of 0.20 €/kWh, the monthly savings from System 1 were approximately €163 in July, compared to only €109 for System 2 in July, which directly impacts the payback period of the investment.
While both systems reduce household electricity bills, the optimally oriented installation provides a significantly higher return on investment [14]. Homeowners with shaded or misaligned systems may need to consider additional solutions, such as micro-inverters or optimisers, to mitigate shading losses [15].

Discussion

The results demonstrate that suboptimal installation conditions can reduce PV energy yield by up to one third, even when identical module technologies and inverters are used. While west-facing systems may still provide valuable afternoon peak generation, shading exacerbates losses and increases system mismatch [16]. For residential applications, careful assessment of roof geometry and shading obstacles is essential to maximize system performance.
Advanced solutions such as power optimizers, micro-inverters, or bifacial modules may partially compensate for shading and orientation issues, though they increase upfront costs. Ultimately, the findings highlight the necessity of proper system design in residential contexts to ensure both economic viability and long-term sustainability [17].

CONCLUSION

This study analyzed the performance of two residential photovoltaic (PV) systems installed under different conditions: one south-facing with optimal orientation, and another west-facing and partially shaded. The comparative analysis highlighted a consistent reduction in energy yield of approximately 30%-35% for the shaded and misaligned system.
The results demonstrate that orientation and shading are critical factors influencing PV system efficiency, with direct consequences on both energy yield and financial viability. While both systems contributed to household energy savings, the optimally oriented installation provided significantly higher production, resulting in shorter payback times and improved long-term benefits. From a practical perspective, the findings emphasize the importance of site assessment prior to installation. Homeowners and installers should carefully evaluate shading obstacles and roof geometry to maximize performance. In cases where optimal orientation is not possible, mitigation strategies such as power optimizers, micro-inverters, or advanced module technologies should be considered.
In conclusion, proper design and installation remain essential to unlocking the full potential of residential PV systems. By minimizing shading effects and ensuring optimal orientation, households can achieve higher efficiency, greater energy independence, and enhanced sustainability, contributing to broader renewable energy integration targets.

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