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Balcony solar photovoltaic plug-and-play systems

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Abstract.

The paper presents balcony solar photovoltaic plug-and-play systems with a capacity of up to 600 W. Balcony solar photovoltaic plug-and-play systems up to 600 W are categorized under plug-in renewable energy production devices. The feasibility of investing in a balcony solar photovoltaic plug-and-play system was analyzed using 15-minute data on electricity consumption for various household consumers. Data on the power density of solar radiation obtained from the online archive of automatic weather stations of the Slovenian Environment Agency were used to calculate the anticipated electricity production of the balcony solar photovoltaic plug-and-play systems. Based on these data, the annual electricity production for various household consumers using a balcony solar photovoltaic plug-and-play system was calculated. The payback period of the investment was calculated considering the current prices of balcony solar photovoltaic plug-and-play systems in the Slovenian market. It also showed how the payback period of the investment is affected by changes in electricity prices for high and low tariffs and by changes in the electricity consumption of the household consumer.

Key words. the photovoltaic system, distributed generation, plug-and-play solar, household consumers, electricity market

1. Introduction

A balcony solar photovoltaic (PV) plug-and-play system is a production device that can be installed on a balcony, roof, or other suitable surface. The advantage of a balcony solar PV plug-and-play system is that it does not require consent from the distribution company for operation, but the connection power must not exceed 600 W [1] and [2]. The regulation on the requirements for low-voltage electrical installations and the Technical Guideline TSG-N-002 must be considered. An expert is not required for installation, as the kit contains everything necessary, and the balcony solar PV plug-and-play system can be assembled and connected by oneself. The electricity produced from the balcony solar PV plug-and-play system is accounted for in 15-minute intervals, while excess electricity produced is fed into the grid without compensation.

Considering the increasing interest in renewable energy and the growing need for sustainable solutions [3], different authors delve into the topic of solar PV plug-and-play systems as a promising avenue for expanding solar energy adoption. A comprehensive analysis by Aishwarya et. al. [4] aims to address regulatory barriers hindering the increased adoption of solar PV systems in the U.S. Their focus on advocating for plug-and-play solar systems involves evaluating compliance with technical and safety standards, identifying non-technical grid entry barriers and proposing streamlined application processes. Aishwarya et. al. [5] anticipate a significant expansion of the U.S. plug-and-play solar PV market, estimating a potential market size of over 57 GW and sales opportunities ranging from $14.3 to $71.7 billion, contingent upon regulatory updates. This shift could substantially boost solar energy production and reduce consumer electricity costs, advancing solar technology adoption. Additionally, Arafat Khan et. al. [6] introduce a plug-and-play PV system to overcome high soft costs associated with traditional installations, potentially reducing residential PV system costs by $0.6/W through streamlined controls and communications.

In this paper, five different profiles of household consumers were selected to calculate the feasibility of investing in a balcony solar PV plug-and-play system. A kit sold on the Slovenian market was chosen to produce electricity using the balcony solar PV plug-and-play system. Based on the data on the balcony solar PV plug-and-play system and measurements of the power density of solar radiation on a 15-minute basis, which was obtained from the meteorological data archive of the Slovenian Environment Agency (ARSO), the anticipated electricity production of the balcony solar PV plug-and-play system was calculated. Subsequently, the calculated electricity production was subtracted from the measured data of electricity consumption at a 15-minute interval, obtaining data on the withdrawal and feed-in of electricity from or into the grid. Based on the electricity consumption from the grid before and after the balcony solar PV plug-and-play system

installation, the annual electricity costs were calculated, considering the electricity billing during higher daily tariffs (HT) and lower tariffs (LT). The difference in electricity consumption costs provided an annual saving, with which the payback period of the investment was calculated based on the varying prices of balcony solar PV plug-and-play systems on the Slovenian market between 600.00 and 1,000.00 EUR. Figure 1 presents different balcony solar PV plug-and-play systems on buildings.

Fig. 1. Different balcony solar PV plug-and-play systems [7].

2. Regulation on technical requirements for connection and operation of plug-in renewable energy production devices

The regulation specifies the technical requirements for the connection and operation of plug-in renewable energy production devices. The development of electronic and electrical equipment in the field of plug-in production devices for renewable sources and devices for electrical energy storage has advanced to such a degree that these devices for producing and storing electrical energy can be used in every household. Conditions for spatial placement (e.g., PV modules on a balcony, terrace, or other suitable surface) must be met, and connection to the household consumer's final circuit must be enabled. A plug-in production device is a device for producing electrical energy from renewable sources, which is connected to the internal electrical installation of the household consumer and operates in parallel with the electrical energy distribution network in accordance with this regulation (article 2 of the Regulation [8]).

A plug-in production device may only be connected to the internal installation of a household consumer that is carried out in accordance with the requirements of the regulation governing low-voltage installations in buildings and meets the requirements of section 11.3.8 on portable photovoltaic devices of the Technical Guideline TSG-N-002 for low-voltage electrical installations, as well as the requirements of this regulation. The plug-in production device must meet the requirements in accordance with the Regulation on Ensuring the Availability of Electrical Equipment on the Market, which is designed for use within certain voltage limits (Official Gazette of the RS, No. 39/16) (article 3 of the Regulation [9]). The household consumer must notify the distribution operator 14 days before the commencement of operation of the plug-in production device. The plug-in production device can feed working power into the electrical energy distribution network at any time, which is equal to or less than 600 W. The energy that the household consumer feeds into the electrical energy distribution network in accordance with this regulation is not recorded at the household consumer's metering point in accordance with the law governing the supply of electricity (article 4 of the Regulation [9]). Thus, the regulation establishes the technical requirements for the connection and operation of plug-in production devices on renewable sources, which were already presented by the author [1] in 2021. A plug-in production device installed on the balcony, comprised of PV modules, is also referred to as a balcony solar PV plug-and-play system.

3. The economic aspect of investing in a balcony solar photovoltaic plug-and-play system

Based on the data regarding the electricity consumption of five different household consumers (four in multi-apartment buildings and one in a single-family house), the average electricity consumption per household consumer was established. The annual electricity consumption for the average household consumer, displayed over 15-minute intervals, was presented, as shown in Figure 2. A billing power of 7 kW with a main fuse of 1 x 20 A was accounted for. Figure 3 presents the monthly statement of electricity consumed, structured as follows: electricity consumed (encompassing all HT and LT energy), network fee (including billing power and network fees for HT and LT), total contributions (comprising contributions to energy efficiency, combined heat and power (CHP) and renewable energy sources (RES), market operator functioning, and excise taxes), and the value-added tax (VAT) (22 % for Slovenia). Consequently, the annual cost for the average household consumer was calculated to be 768.32 EUR with VAT, or an average monthly cost of 64.03 EUR with VAT. The average household consumer's annual electricity consumption was recorded at 3,537.9 kWh, with the average

monthly electricity consumption being 295 kWh. Figure 4 presents the distribution of the number of 15-minute readings in relation to the electricity consumed.

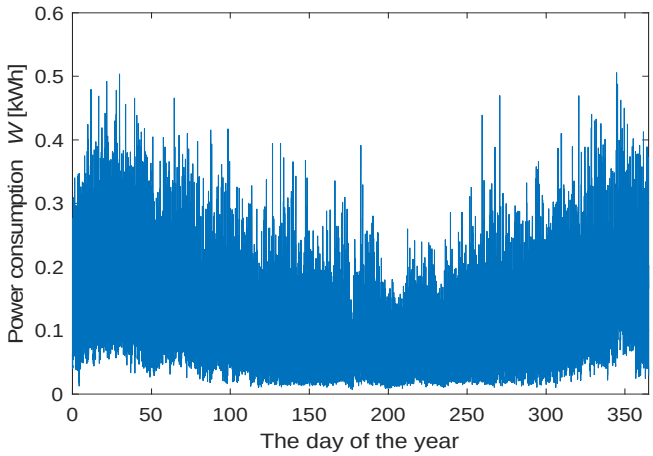

Fig. 2. Electricity consumption for a period of one year.

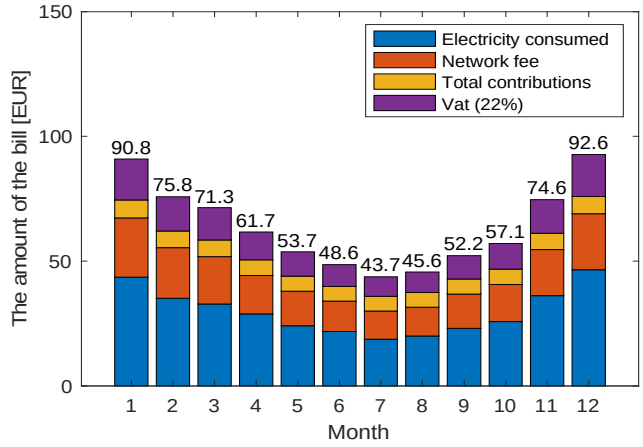

Fig. 3. Monthly statement of electricity consumption for the average household consumer.

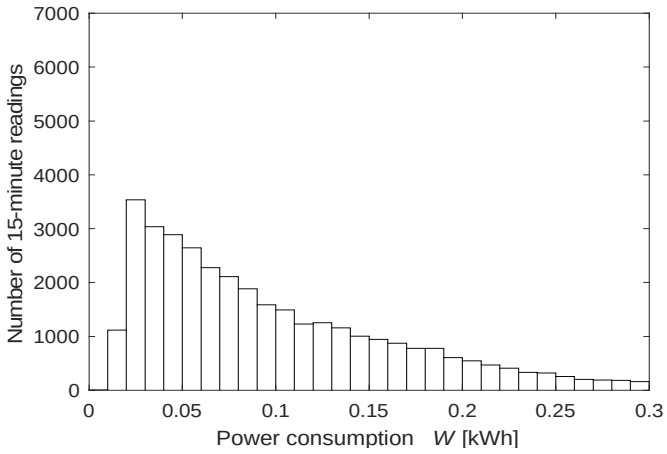

Fig. 4. Distribution of the number of 15-minute readings in relation to the electricity consumed.

Figure 4 reveals that, within the analyzed example, there exists a span of 48 days (accounting for 13% of the entire year) where electricity consumption ranges from 0 to 30 Wh (0.03 kWh), and a further 172 days (representing 47 % of the year) where consumption lies between 30 and 100 Wh (0.1 kWh). For 40 % of the year, consumption surpasses 100 Wh within each 15-minute measurement interval. The annual average electricity consumption is determined to be 0.10 kWh, with the peak consumption in a single 15-minute interval reaching 0.51 kWh in December.

The analysis assumes the use of a balcony solar PV plug-and-play system as the plug-in production device, equipped with PV modules totaling 600 W in power at 20% efficiency, a micro-inverter, and a connecting cable with a plug for straightforward integration into a household's final circuit. In Slovenia, the market price for such systems currently spans from 600.00 EUR to 1,000.00 EUR, VAT included. Leveraging data on the global and diffuse solar radiation power density sourced from ARSO, along with considerations for the solar modules' slope and azimuth angles, module efficiency, and inverter efficiency, we have projected the electricity output for the balcony solar PV plug-and-play system and utilized this in evaluating the viability of this investment.

4. Results

The economic outcomes of calculation for using a balcony solar PV plug-and-play system are presented herein. The actual electricity consumption for the average household consumer and the projected electricity production from the balcony solar PV plug-and-play system for the calendar year were incorporated (shown in Figure 5). Calculations were conducted in 15-minute intervals, with consideration given to electricity consumption during HT and LT periods. The anticipated electricity consumption of a household utilizing a balcony PV plug-and-play system is displayed in Figure 5.

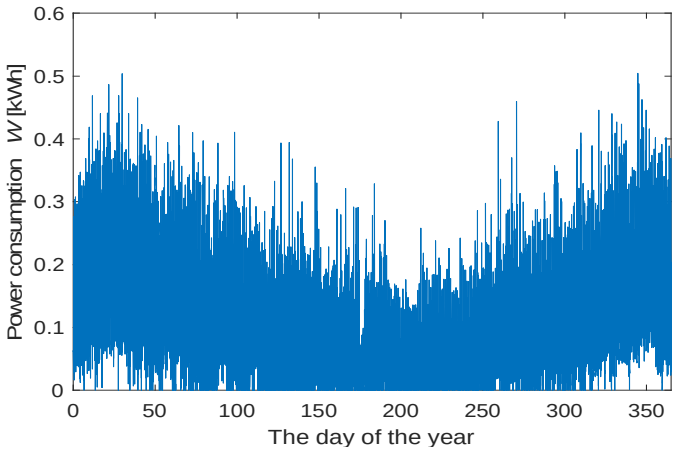

Fig. 5. Electricity consumption using balcony solar PV plug-and-play system for a period of one year.

Figure 6 shows the monthly statement of electricity consumed with a balcony solar power plant for the average household consumer, while Figure 7 presents the distribution of the number of 15-minute readings in relation to the electricity consumed with a balcony solar power plant for the average household consumer.

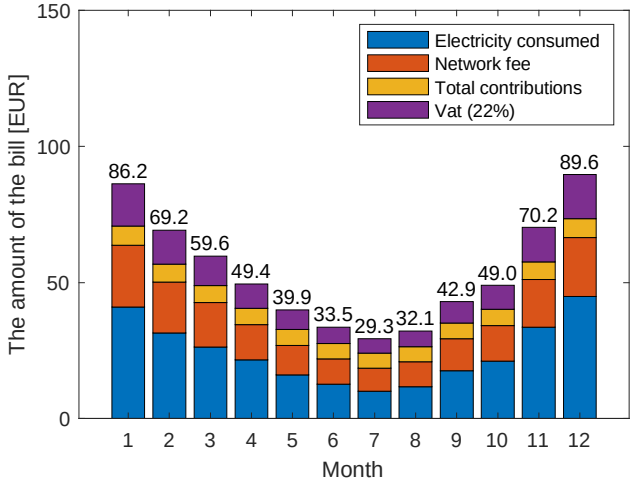

Fig. 6. Monthly statement of electricity consumption for the average household consumer using balcony solar PV plug-and-play system

From Figure 7, it is observed that in 29 % of the year (106 days), electricity consumption is recorded between 0 and 30 Wh. In 39 % of the year (142 days), consumption is found to be between 30 and 100 Wh, while in 32 % of the year, consumption exceeds 100 Wh in each 15-minute interval. With the projected electricity production from the balcony solar PV plug-and-play system and the annual electricity consumption considered, it can be concluded that the monthly electricity bill is reduced by 15 %. As a result, the annual electricity expenditure for the average household consumer would be reduced from 768.32 EUR to 651.41 EUR, inclusive of network fees, contributions, and taxes, amounting to a saving of 116.92 EUR.

Thus, the investment's payback period is determined to be between 5 and 9 years. The payback period of the investment as a function of electricity consumption and prices of HT and LT electricity is depicted in Figure 8.

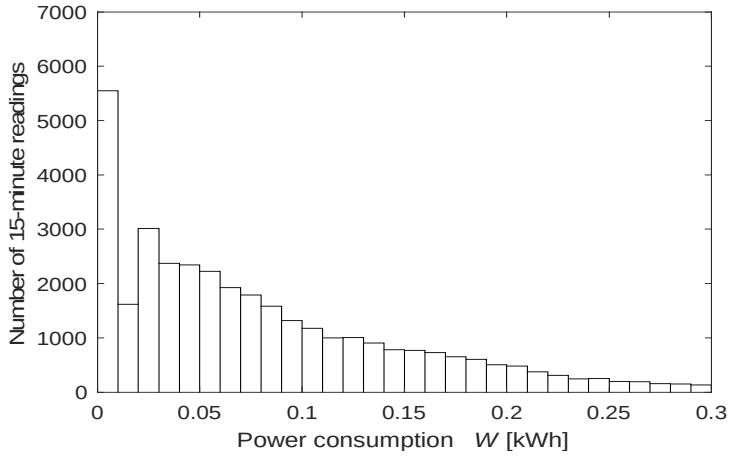

Fig. 7. Distribution of the number of 15-minute readings in relation to the electricity consumed using balcony solar PV plug-and-play system

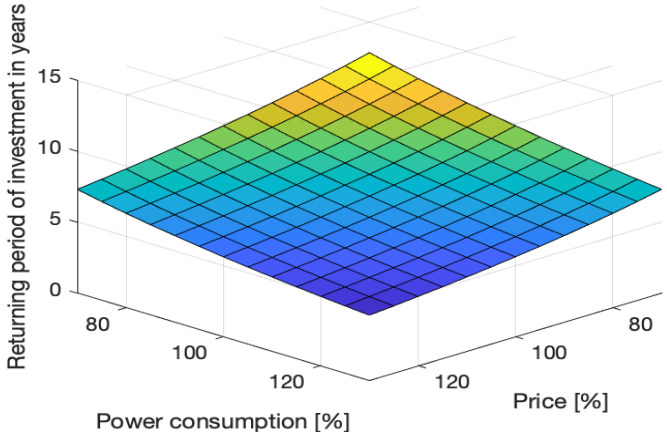

Fig. 8. The payback period of the investment as a function of electricity consumption and prices of HT and LT electricity.

Figure 8 shows that with a 30 % increase in the prices of HT and LT electricity and a 30 % increase in electricity consumption, the payback period of the investment is the shortest, at 4.57 years. Considering the current price of electricity and a 30 % reduction in electricity consumption, the payback period of the investment extends to 8.73 years. With the actual consumption of electricity and a 30 % increase in the prices of HT and LT electricity, the payback period is 5.64 years. The longest payback period, which amounts to 10.83 years, is achieved with a 30 % reduction in the prices of HT and LT electricity and a 30 % reduction in electricity consumption. An analysis considering the economic aspects was conducted for six different household consumers (HC) – Table 1.

Table 1. Description of different household clients.

	HC 1	**HC 2**	**HC 3**	**HC 4**	**HC 5**	**HC 6**
Area [m^2]	60	35	35	74	135	68
Power consumption [kWh]	2.738	2.594	751	4.777	6.829	3.538
The main fuses [A]	1x35 (7 kW)	1x25 (6 kW)	1x35 (7 kW)	1x25 (6 kW)	3x20 (7 kW)	1x20 (7 kW)
Type of heating	DH*	DH*	DH*	IR panels	heat pump	/

* DH – district heating

Figure 9 displays the payback period of the investment for six different household consumers. This timeframe, in which the investment in a balcony solar PV plug-and-play system pays off, is crucial in assessing the economic viability of such an investment.

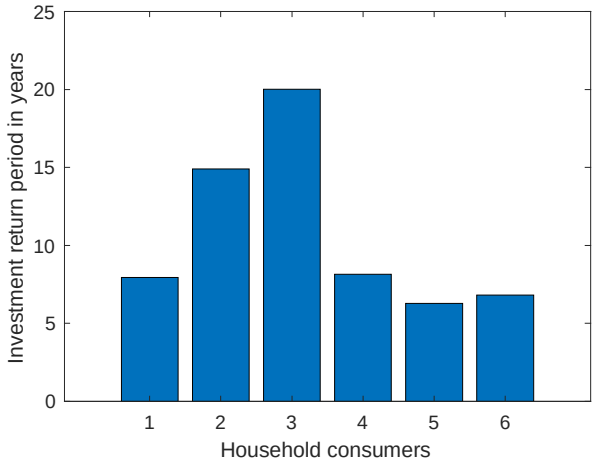

Fig. 9. The payback period of the investment for different household consumers.

From Figure 9, the investment in a balcony solar PV plug-and-play system is recouped in a shorter period for household consumers 1, 4, and 5, which is attributed to their consistent electricity consumption throughout the year. The payback period for the investment is extended for household consumers 2 due to higher electricity consumption in the winter months when electricity production is diminished. For household consumer 3, the longest payback period is observed, resulting from the very low electricity consumption, despite it being consistent year-round.

5. Conclusion

In the paper, the justification for investing in a balcony solar PV plug-and-play system with an installed capacity of up to 600 W, which is connected as a plug-in production device, is presented. From the results presented in the paper, it is determined that such an investment pays off in a relatively short time, ranging from 4 to 9 years. The balcony solar PV plug-and-play system proves to be a sensible solution in multi-apartment buildings, especially for consumers with higher and consistent electricity consumption throughout the year. However, it is important to note that the payback period of the investment can vary significantly depending on the specific conditions and consumption profile of each household consumer. In older buildings with TN-C or TN-C-S systems, integrating a balcony solar power plant into the low-voltage network can cause issues with the operation of the residual-current device (RCD), leading to unnecessary tripping of the protection. It is also sensible to consider other factors such as spatial constraints and the rules of multi-apartment buildings regarding the installation of such systems. Therefore, using balcony solar power plants requires a comprehensive approach and careful planning.

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