

PV panels as a renewable energy source for residential building – an economical comparison before and during the energy crisis

Michal Brandtner^{1*}, Vaclav Sotolar¹, Adam Bohacek¹ and Vaclav Venkrbec^{1,2}

¹ Brno University of Technology, Faculty of Civil Engineering, Veveri 331/95, 60200 Brno, Czech Republic

² UiT The Arctic University of Norway, Faculty of Engineering Science and technology, Lodve Langesgate 2, 8514 Narvik, Norway

Abstract. The application of renewable energy sources is a current trend today due to the limited sources of fossil. A substantial part of these energy sources is solar radiation. The development of electricity prices was significantly affected by two global crises, the COVID-19 pandemic and the energy crisis associated with the Russia-Ukraine conflict. The essence of the article is to compare the economic sense and appropriateness of investing in a photovoltaic power plant system and its return over time, considering the prediction of the development of electricity prices between 2020 and 2023 and subsequently also with a 15-year price prediction. The article deals with investment, energy consumption and financial evaluation of a PV system with PV panels installed on the ventilated façade of a residential building in the Czech Republic. The conclusions of the article show that the increase in investment in the PV panels themselves between 2020 and 2023 is a crucial factor for the return of the entire system. Predictive models of the development of electricity prices and associated liquidity of the investment also play a significant role in this issue.

1 Introduction

European countries have agreed on a new 2030 Framework on climate and energy, which sets a target for the share of renewables to reach at least 27 % of the gross final energy consumption of the European Union by 2030 [1]. The development of renewable energy sources is a promising concept to tackle climate change and reduce greenhouse gas emissions [2]. It also aims at reducing energy dependency between countries [3], which has been a current characteristic goal for most European countries in recent years, among other reasons due to the energy crisis resulting from the ongoing Russia-Ukraine conflict [4].

The development of electricity prices was significantly influenced by two global crises, the COVID-19 pandemic and the energy crisis associated with the Russian-Ukrainian conflict [4]. On the basis of global crises, the price of electricity is rising. However, many developed European countries want to be independent from Russia and other great powers, so they are

* Corresponding author: 159111@vutbr.cz

looking for a solution to the energy crisis in renewable sources [5]. The production of these systems very often ends up depending on another commodity that the country is unable to produce on its own.

Photovoltaic panels are used for the production of electrical energy, which is produced thanks to light radiation, but not thermal radiation. The most famous photovoltaic panels are made of silicon cells (crystalline cells), in which direct current is generated. The produced current is led by special cabling to the voltage converter. Direct current is converted into alternating current. From there, the electric current is distributed to the battery storage of electrical energy, or to the home electrical grid. In the event of a surplus of electricity, energy can be supplied to the distribution electricity network.

Photovoltaic energy production is one of the fastest growing energy sources, which is influenced by the amount of sunlight and the temperature of the photovoltaic panel. The efficiency of photovoltaic panels decreases with increasing temperature. Article [6] deals with the experimental investigation of photovoltaic panel performance using phase change materials. These materials can absorb a significant amount of heat when used on the back of the panel, increasing their output power.

PV cell is a device that converts solar energy directly into electricity. PV cells are made from materials we call semiconductors. The basic material of the semiconductor is silicon. However, it has the disadvantage that in its raw state it is a very poor conductor of electricity. For this reason, silicon is combined with other elements like phosphorus and boron. Semiconductors created by mixing silicon and phosphorus have an excess of electrons. These semiconductors are referred to as N-type semiconductors. Semiconductors that are created by mixing silicon and boron, on the other hand, are deficient in electrons. Places where electrons are missing are called holes. These holes have a positive electric charge, so we call these semiconductors P-type semiconductors. If we connect an N-type and a P-type semiconductor together, the electrons begin to spontaneously move toward the P-type semiconductor and the holes begin to move toward the N-type semiconductor. In places where these semiconductors are connected is a barrier that prevents electrons and holes from moving across the entire semiconductor. When the PV cell is irradiated with sunlight, this barrier is overcome, and the electrons penetrate into the P-type semiconductor and the holes into the N-type semiconductor. This creates an electric voltage on the PV cell [7]. The following kinds of PV panels are currently known: (a) Silicon crystalline solar panel; (b) Thin film solar panels; (c) Perovskite solar cells; (d) Organic solar panel; (e) Photovoltaic double-shell panels (PV-DSF); (f) Building Integrated Photovoltaics (BIPV); (g) Photovoltaic façades [7, 8, 9].

The history of photovoltaic panels dates back to the 50s of the last century, when scientists first discovered the photovoltaic effect. The first solar-powered building was built in 1979, and the use of PV panels on building façades has grown steadily since then. Nowadays, the use of photovoltaic panels on building façades is becoming increasingly popular and the market is growing rapidly. This trend is driven by the growing interest in renewable energy sources as well as efforts to reduce energy costs and reduce the carbon footprint of buildings. In recent years, building-integrated photovoltaics (BIPV), where PV panels are integrated into the design of the building rather than being added as an afterthought, has become more popular. This approach allows for more aesthetically pleasing designs and has helped to dispel the notion that PV panels are unattractive and detract from the appearance of a building.

In addition, the development of smart grid technology will allow building owners to better manage energy consumption and integrate their PV panels into the larger energy grid, further reducing costs and increasing the efficiency of the technology.

From the above, it can be logically deduced that façade systems are currently unique and have not been subjected to the necessary studies. The aim of this article is to explore one such solution, in this case on a specific case study of an apartment building in the Czech Republic.

This paper fills a gap in the literature and contributes to the overall expansion of knowledge in the field of photovoltaic systems.

The following chapters of the paper are structured as follows: chapter 2 presents the methods and background facts about the case study, chapter 3 summarizes the findings and discusses them, and is followed by chapter 4, which summarizes the main highlights and provides conclusions.

2 Methods

2.1 Parameters for installing PV panels on the façade

PV panels can be placed on the façade for architectural reasons or because they cannot be placed on the roof structure for other reasons. The best efficiency of photovoltaic panels is usually when installed at an inclination of 30° to 40°. Another important aspect in the placement of photovoltaic panels is the orientation to the cardinal directions as shown in Figure 1 [10].

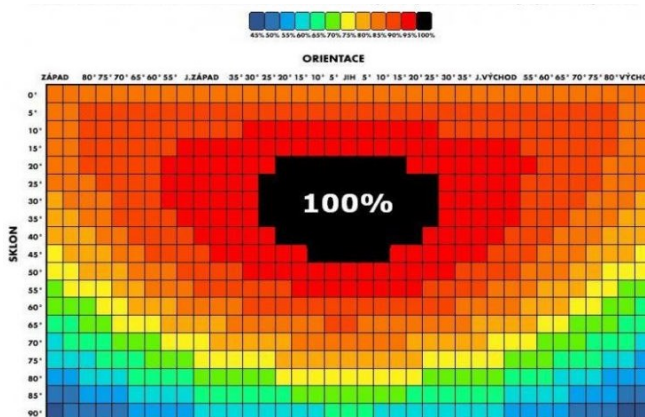


Fig. 1. Effect of orientation to cardinal directions and inclination of PV panels on their performance [10].

The ideal placement is on the south façade, while the north façade is not suitable. On the façade, PV panels can be placed at 90° and serve as the top layer of a ventilated. Panels mounted completely vertically show an efficiency loss of about 25 % compared to panels at an optimum inclination of 35°. This placement is most common in cases where the aim is not to disturb the architecturally determined mass of the building, as visible in Figure 2. Another option is to install the panels at a lower angle, which usually increases the efficiency of energy production, but at the detriment of poorer aesthetics and possible shading of the building interior. Such an installation is suitable, i.e. for office spaces. The PV plant has a total area of 53.6 m². The most important value in the calculation is also the average daily sunshine. In recent years, the average daily sunshine was 8 hours, however, only 5 hours of sunshine has been considered, due to the lower electricity production and the earlier eventual financial return of the PV plant. In the case study presented below, option b) was chosen, i.e. the placement of the PV panels at 90°, and only on the south façade of the building.

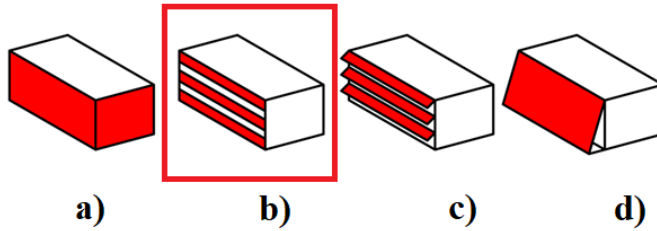


Fig. 2. Options for placing photovoltaic panels on the façade of a building with a selected option for a case study [11].

2.2 Reference building for case study and calculation of electricity consumption

The case study considers the possibility of using solar energy for the needs of an apartment building consisting of three floors above ground and one underground floor. 3D model of building is visible in Figure 3. There are three apartments on each floor and Table 2 shows the reference set of domestic appliances and their average running time per day. The basic parameters of the PV system are shown in Table 1. The PV panels are fixed to a support grid, which is further anchored within the south façade of the building to the supporting structure. The electricity generated will be stored in LiFePO₄ batteries and in case of surplus electricity will be transferred to the distribution grid.



Fig. 3. 3D model of case study reference building [authors own work].

Table 1. Basic parameters of PV panels.

Dimensions	Atypical	Nominal voltage	43.4 V
Cell type	Mono-crystalline	Max. load current	9.22 A
Nominal panel output	400 Wp	Voltage at idle	52.7 V
Weight per 1 m²	12 kg	Max. system voltage	1000 V
Warranty period	25 years	Total area of PV panels	53.6 m ²
Max. panel efficiency	19.4 %	Average daily hours of sunshine	5 hours

Table 2 shows the electricity consumption per 1 year. Each housing unit consumes approximately 23.6 kWh per day and 212.0 kWh of electricity is consumed per day in total.

The total electricity consumption of the apartment building for 1 year is 77,388 kWh. Then, the electricity production of the PV power plant per 1 year is shown in Table 3.

Table 2. Electricity consumption of an apartment building.

Appliance type	Average power input [kW]	Appliance use time [hours]	Daily consumption [kWh]
Household lighting	0.80	2.5	2.0
Electric boiler, volume 200 l	2.20	1.0	2.2
Electric hair dryer	2.30	0.15	0.3
Combined fridge	0.30	1.0	0.3
Electric kettle	2.20	0.25	0.6
Microwave oven	0.90	0.25	0.2
Built-in oven	3.30	0.5	1.7
Electric induction cooktop	6.50	1.0	6.5
Electric cooker hood	0.08	1.0	0.1
Dishwasher	0.80	1.5	1.2
Washing machine	1.00	1.0	1.0
Clothes dryer	4.50	1.0	4.5
Wi-Fi router	0.01	24.0	0.2
LCD TV	0.20	2.0	0.4
Total electricity consumption of 1 apartment unit per day [kWh]			23.6
Number of apartment units in the apartment building [pcs]			9
Total electricity consumption of the apartment building per day [kWh]			212.0
Total electricity consumption of the apartment building per 1 year [kWh]			77.388

Table 3. Electricity production of the PV power plant per 1 year.

Generated power of one panel per 1 m² [Wp] per hour	400
PV panel efficiency at 90° inclination [%]	70
Actual power of one panel per m² [Wr] per hour	280
Total PV panel area [m²]	53.6
Electricity produced per hour [kW]	15.01
Average daily sunshine time [hours]	5
Total electricity produced per day [kWh]	75.04
Total electricity produced per year [kWh]	27 389.6

3 Results and discussion

The objective of the case study was to find out how long it takes for a PV plant to be profitable. That is, how long it takes to return to the investor the initial cost that was invested. Table 4 shows the calculation of the cost of a PV power plant for the façade of an apartment building. The calculation takes into account the administrative work, the actual installation and delivery of the PV plant to the final site and its installation. The total cost of the PV power plant is € 27,627 in 2020 and € 43,073 in 2023 as shown in Table 4. No state or other subsidies were considered.

The return calculation for the PV system implemented in 2020 is shown in Table 5. There is a visible decrease in efficiency over time. Also, the change in the unit market price of electricity has a substantial role in the return on investment. This parameter has been taken for the study from the Energy Brainpool 2022 forecasting model [12], which assumes a rapid decrease in the market price of electricity after 2030. This results in a slower return on investment in the single years after 2030. This trend is also evident in the sniff chart in Figure 6. Energy consumption is assumed to be constant in future years. This parameter is also

questionable given the tendency of end users to behave responsibly and sustainably and to save electricity.

Table 4. Total cost of the PV power plant for the apartment building in 2020 and in 2023.

Item	Pcs	Unit	Unit cost in 2020 [EUR]	Unit cost in 2023 [EUR]	Cost of item in 2020 [EUR]	Cost of item in 2023 [EUR]	Difference (2023-2020) [EUR]
PV power plant project documentation	1	set	133	626	133	626	493
PV panel	45	pcs	246	441	11 080	19 861	8 782
Solar cable 6 mm²	5	100 m	95	144	473	720	246
Connectors for PV panels	90	pcs	1	1	68	128	60
PV panel anchoring system	132	pcs	5	20	650	2 683	2.033
Combined voltage inverter	1	pcs	337	1 487	337	1 487	1.150
Voltage regulator	2	pcs	57	109	114	218	104
Battery	1	pcs	11 932	13 281	11 932	13 281	1 349
Installation costs of the PV power plant	1	set	2 841	4 069	2 841	4 069	1 228
Total cost of the PV power plant for the apartment building					27 672	43 073	15 446

Table 5. Returns calculation of the PV power plant for the apartment building, constructed in 2020.

Years of service	Efficiency [%]	Generated electricity [kWh]	Unit market price per 1kWh [EUR]	Market value of electricity produced in a given year [EUR]	Electricity consumption in a given year [kWh]	Market price of electricity consumed in a given year [EUR]	Returns [EUR]
2020	70	27 389.6	0.1894	5 187.42	77 388.0	14 656.82	5 187.42
2021	69	26 998.3	0.2201	6 817.08	77 388.0	14 656.82	12 004.50
2022	68	26 607.0	0.2525	6 718.28	77 388.0	14 656.82	18 722.78
2023	67	26 215.8	0.2475	6 488.29	77 388.0	14 656.82	25 211.07
2024	66	25 824.5	0.1722	4 445.92	77 388.0	14 656.82	29 656.99
2025	65	25 433.2	0.1263	3 210.94	77 388.0	14 656.82	32 867.93
2026	64	25 041.9	0.0976	2 443.01	77 388.0	14 656.82	35 310.94
2027	63	24 650.6	0.0803	1 980.45	77 388.0	14 656.82	37 291.39
2028	62	24 259.4	0.0780	1 893.33	77 388.0	14 656.82	39 184.73
2029	61	23 868.1	0.0735	1 753.22	77 388.0	14 656.82	40 937.95
2030	60	23 476.8	0.0689	1 616.70	77 388.0	14 656.82	42 554.64
2031	59	23 085.5	0.0666	1 536.76	77 388.0	14 656.82	44 091.40
2032	58	22 694.2	0.0643	1 458.62	77 388.0	14 656.82	45 550.03
2033	57	22 303.0	0.0620	1 382.28	77 388.0	14 656.82	46 932.30
2034	56	21 911.7	0.0608	1 332.88	77 388.0	14 656.82	48 265.18
2035	55	21 520.4	0.0597	1 284.38	77 388.0	14 656.82	49 549.56
2036	54	21 129.1	0.0585	1 236.77	77 388.0	14 656.82	50 786.33
2037	53	20 737.8	0.0574	1 190.07	77 388.0	14 656.82	51 976.40

From Figure 4 it can be seen that the investment made in 2020 is discarded after 4 years of operation, when revenues of 25 thousand € have been achieved in this year, on the contrary, according to Figure 6, the investment relayed in 2023 is not discarded even after 15 years of operation. The unit price of electricity plays a key role in this difference, and the increased cost of procurement also plays a relatively significant role. The total cost of acquiring an identical PV plant has increased from €27 672 to €43 073 over three years, an increase of €15 401, an increase in input costs of 55.6 %.

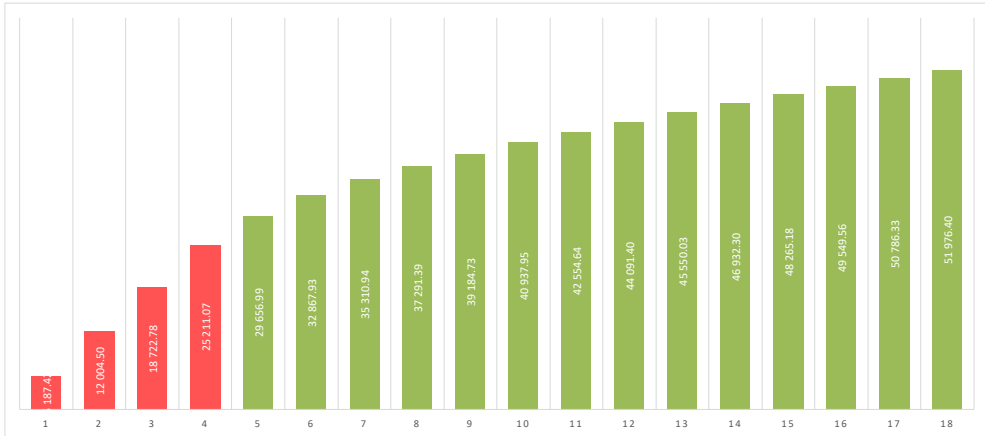


Fig. 4. Model of financial return on PV power plant in € – constructed in 2020.

Analogically, as the return for 2020 was calculated, the return for the PV plant implemented in 2023 was calculated in the same way, as can be seen in Table 6 and Figure 5.

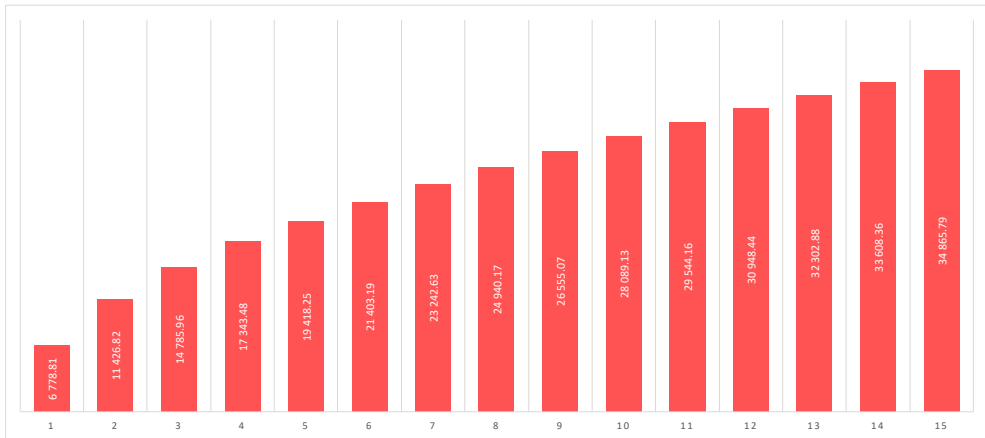


Fig. 5. Model of financial return on PV power plant - constructed in 2023.

Table 6. Returns calculation of the PV power plant for the apartment building, constructed in 2023.

Years of service	Efficiency [%]	Generated electricity [kWh]	Unit market price per 1kWh [EUR]	Market value of electricity produced in a given year [EUR]	Electricity consumption in a given year [kWh]	Market price of electricity consumed in a given year [EUR]	Returns [EUR]
2023	70	27 389.6	0.2475	6 778.81	77 388.0	19 153.21	6 778.81
2024	69	26 998.3	0.1722	4 648.01	77 388.0	19 153.21	11 426.82
2025	68	26 607.0	0.1263	3 359.14	77 388.0	19 153.21	14 785.96
2026	67	26 215.8	0.0976	2 557.53	77 388.0	19 153.21	17 343.48
2027	66	25 824.5	0.0803	2 074.76	77 388.0	19 153.21	19 418.25
2028	65	25 433.2	0.0780	1 984.95	77 388.0	19 153.21	21 403.19
2029	64	25 041.9	0.0735	1 839.44	77 388.0	19 153.21	23 242.63
2030	63	24 650.6	0.0689	1 697.53	77 388.0	19 153.21	24 940.17
2031	62	24 259.4	0.0666	1 614.90	77 388.0	19 153.21	26 555.07
2032	61	23 868.1	0.0643	1 534.07	77 388.0	19 153.21	28 089.13
2033	60	23 476.8	0.0620	1 455.03	77 388.0	19 153.21	29 544.16
2034	59	23 085.5	0.0608	1 404.28	77 388.0	19 153.21	30 948.44
2035	58	22 694.2	0.0597	1 354.43	77 388.0	19 153.21	32 302.88
2036	57	22 303.0	0.0585	1 305.48	77 388.0	19 153.21	33 608.36
2037	56	21 911.7	0.0574	1 257.43	77 388.0	19 153.21	34 865.79

A comparison of the two realisations, i.e. in 2020 and 2023, can be seen in the graph in Figure 6. The trend curves for the incremental return on investment in each year can be seen here. Although the logarithmic progression of the curves is not too different, the upfront investment costs play a significant role, where these costs shift the curve upwards on the y-axis and thus delay the amortisation of the investment in subsequent years.

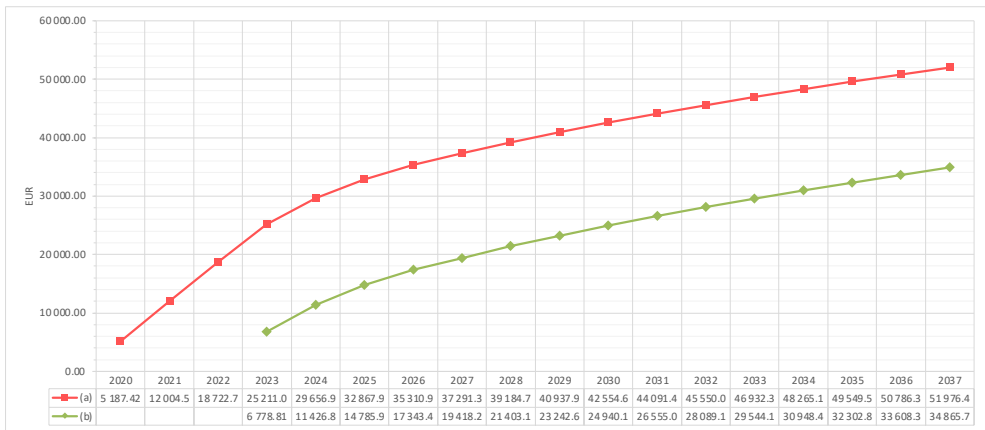


Fig. 6. Comparison of the return on investment of the PV power plant: (a) constructed in 2020; (b) constructed in 2023.

The results also showed how much electricity can be generated by a PV plant on the façade of an apartment building. Furthermore, the study shows the differences in initial costs and returns of a PV plant when implemented in 2020 and in 2023. An important aspect in the calculation is the power of one PV panel. The proposed PV panel of 400 Wp is mounted at an inclination of 90°. This inclination is undesirable in terms of PV performance, dropping to 70 % of full power. PV plants have an average lifetime of 20-25 years. In the calculation of electricity production, a 15-year lifetime was considered due to the reasonable financial

return of PV plants being between 10-15 years on building façades. A decrease in energy production with each year of 1 % is considered as a gradual degradation of PV panels. Results showed that with each year used, the electricity production of PV façade on the apartment building decreases by 39.31 kWh. From 5 year to 10 year, the electricity production decreases by 9782.0 kWh. The comparison with the electricity produced by PV façade in 1 year and the electricity consumption of apartment building in 1 year is around one third.

4 Conclusion

The aim of the paper was to examine the role of the energy crisis in the context of the Russia-Ukraine conflict. The conflict occurred shortly after the global pandemic COVID-19. It was found that the unit price of electricity plays a relatively significant role in the amortisation of the initial investment in a PV system for a smaller 9-unit apartment building. The increased purchase cost is also a key factor. It increases by 55.6 % between 2020 and 2023. The total cost of purchasing an identical PV system has increased from €27 672 to €43 073 over three years.

Based on the results of the case study, the following highlights can be summarised:

- A key starting point for early returns is the initial cost of a PV system.
- The unit cost of electricity is a key parameter affecting the returns from a PV system.

This can be a side effect of global crises.

- Global crises have only a secondary impact on PV system returns, such as pandemics or wars. Their duration is usually short and the calculation of returns is over a longer time horizon.

- The amortisation of the upfront investment in a PV system is significantly affected by local and supranational legislation regulating electricity prices. This is therefore one of the secondary effects of the global crises and wars.

At a time when electricity prices are on the rise in many EU countries, the investment in a PV system and other renewable energy sources is a matter of concern for many property owners in order to avoid future problems with energy costs and is a key issue in the operation of the building. This article fills a gap in the literature of the last few years, which have been affected by crises of various origins. In addition, it provides a guide for the owners and investors of new buildings on how to approach the financial equilibrium in the implementation of a PV power plant on the façade of an apartment building. The article also describes and reflects on current trends and parameters that influence the market.

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