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# Chapter 2. Comparison of Forecasted and Actual Energy Yields from PV Installations. Integration with Energy Storage Systems

*Martyna KOŻUCHOWSKA, Marcin A. SULKOWSKI*
*Bialystok University of Technology, Faculty of Electrical Engineering,*
[1]*e-mail: 83763@student.pb.edu.pl*
[2]*e-mail: m.sulkowski@pb.edu.pl*

**Abstract.** This chapter analyzes and compares the forecasted energy yields from a photovoltaic installation generated using several simulation programs with the actual energy production from the installation. It also discusses the advantages and disadvantages of energy storage systems and identifies scenarios where their use is beneficial. Simple payback periods are calculated for two PV installation variants to compare investment return times.

**Streszczenie.** W rozdziale przeanalizowane i porównane zostały prognozowane uzyski energii z instalacji fotowoltaicznej wygenerowane za pomocą kilku programów symulacyjnych, a następnie zostały one porównane z rzeczywistą produkcją energii przez instalacje. Omówiono także zalety i wady tego rozwiązania oraz to, kiedy i dla jakich instalacji warto zastosować magazyn energii. Wyznaczone zostały również proste okresy zwrotu dla dwóch wariantów instalacji PV w celu porównania czasu zwrotu inwestycji

**Słowa kluczowe:** magazynowanie energii, efektywność energetyczna, odnawialne źródła energii, fotowoltaika

**Keywords:** energy storage, energy efficiency, renewable energy sources, photovoltaic installations

## Introduction

Due to the continuous rise in electricity prices, an increasing number of individuals are choosing to install photovoltaic systems in their homes or businesses. The primary goal is to achieve greater independence from the public power grid. When combined with an energy storage system, such installations allow users to utilize the energy generated by their own PV system at a later time, particularly when the system is not actively producing electricity. Currently, this is the most popular and widely accessible solution for acquiring electricity from renewable energy sources. This trend has been largely driven by ongoing technological advancements, which have led to reduced installation costs and improved system efficiency.

One of the key characteristics of PV installations is the variability of energy production depending on the time of day, season, and weather conditions. Such fluctuations can disrupt the operation of the power grid, leading to phenomena such as voltage increases or distortions in other parameters that define energy quality. Energy storage systems help stabilize grid parameters by enabling energy to be fed into the grid during periods of high demand or allowing users to purchase energy when prices are low and use it when prices are high.

A crucial factor influencing the decision to install a PV system is its profitability and payback period, which depend on the amount of energy the system can produce. During the design phase, a report is generated that presents the forecasted energy yield of a specific PV installation based on input data provided to the simulation software. This raises an important question: will the forecasted energy yield reflect the actual energy production of the PV system? Many prospective PV system owners wonder whether discrepancies between forecasted and actual production will occur, and if so, how significant they will be. Will these differences affect the payback period and overall profitability of the installation? Will it be possible to store some of the energy and use it during periods when the system is not producing?

Therefore, it is worthwhile to analyze the data obtained from PV system simulations and compare them with the actual energy production of a PV installation located and configured according to the simulation parameters.

## Technical Data of the PV Installation and Panel Layout

The analyzed photovoltaic installation has a total capacity of P = 49.92 kW and is mounted on a flat roof covered with roofing felt. The system comprises:

- 104 monocrystalline photovoltaic modules, each rated at P = 480 Wp;
- A P = 50 kW **inverter**.

The panels are oriented **southward** and mounted on ballasted support structures with a tilt angle of 15°. The installation is located in Bialystok, Poland (geographical coordinates: 23°10'E, 53°08'N), and all simulation scenarios are based on this location.

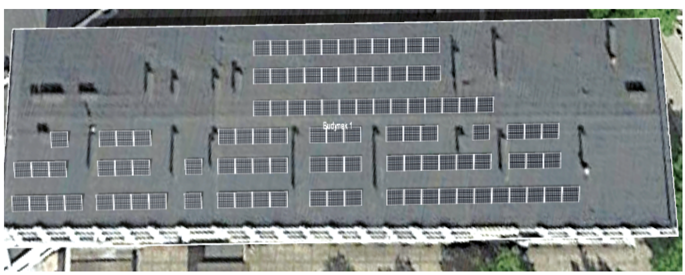

FIGURE 1. Top-down view of the building's roof with the photovoltaic panel layout generated using Sunny Design [5]

The actual layout of the photovoltaic panels on the roof was modeled using the Sunny Design software, which is dedicated to forecasting electrical energy production. The layout reflects the real-world configuration of the system.

## Factors Affecting the Energy Output of a Photovoltaic Installation

The efficiency and energy yield of a photovoltaic system are influenced by a wide range of factors, which can be broadly categorized into **environmental** and **technical** parameters.

## Initial Design Considerations

During the early design phase of a PV installation, the building's electricity consumption profile is analyzed, typically using a network analyzer, to determine its energy demand characteristics. This enables the designer to tailor the system's size and orientation so that the highest energy production coincides with peak consumption periods.

## Environmental Factors

The most critical environmental factor is solar irradiance, which depends on:

- The geographic location of the PV system.
- The tilt angle of the panels relative to the sun's rays.
- The azimuth, i.e., the directional orientation of the panels.

If the system lacks energy storage and peak consumption occurs in the morning and afternoon, an east-west orientation may be optimal. Although this configuration slightly reduces the total annual energy yield compared to a south-facing setup, it better aligns the production curve with the building's consumption profile. Conversely, a south-facing system without storage maximizes annual output and is ideal when peak demand occurs around midday.

If the system includes energy storage, surplus energy can be stored and used during non-generating hours or when electricity prices are high. This increases self-consumption and improves economic performance.

## Temperature Effects

Temperature is another key factor. PV module datasheets specify a temperature coefficient, typically ranging from −0.3%/°C to −0.4%/°C. While standard testing occurs at 25°C, real-world operating temperatures are often significantly higher. As temperature increases, module power output decreases proportionally. Thus, on hot sunny days, module efficiency may be lower than on cooler days with strong irradiance.

## Shading and Surroundings

Beyond selecting an appropriate location and system parameters, special attention must be paid to the surrounding environment. A major issue is shading, caused by nearby trees, buildings, or chimneys. If even a fragment of one panel in a string is shaded, the performance of the entire series-connected group drops to the level of the weakest (i.e., shaded) cell. In practice, this leads to significant losses in total energy production from the PV system [1].

One method to mitigate such losses is the use of bypass diodes, which allow electrical current to flow around shaded cells. These diodes enable energy to bypass the affected panel, minimizing production losses.

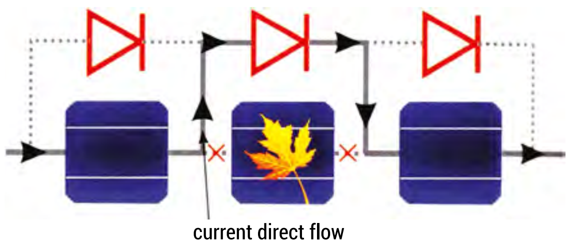


FIGURE 2. Example of bypass diode application, current flow through PV cells when one cell is shaded [2]

## Technical Components

Another critical factor is the selection of system components. The market offers PV modules with varying power ratings, silicon structures, and efficiencies. Choosing modules with higher efficiency, defined as the ratio of electrical energy output to solar energy input, allows for greater energy yield from a given surface area.

The inverter to which the PV panels are connected also plays a significant role. Key considerations include:

- Number of MPPT inputs (Maximum Power Point Tracking): If the system has only one MPPT input, shading of a single module causes the entire system to operate at the reduced power level of the shaded module. In contrast, systems with multiple MPPT inputs allow unaffected panel groups to continue operating at full

capacity. This is especially beneficial in installations with panels oriented in different directions (e.g., east and west), where strings can be separated and connected to individual MPPT inputs to optimize performance.
- DC input voltage: Lower voltage thresholds enable the system to begin energy production at lower irradiance levels. This means that on days with weak sunlight, the system can start generating energy earlier, increasing the total daily yield.

In summary, careful selection of system components and installation parameters, tailored to the building's energy consumption profile and environmental conditions, is essential for maximizing the efficiency and profitability of a PV installation.

## Analysis and Comparison of Simulation Results from Various Software Tools with Actual Energy Production from the PV Installation

To simulate the energy yields of a photovoltaic installation, dedicated software tools can be used. This enables a comparison between forecasted results and actual energy production. In this study, simulations were conducted using three programs: PV*SOL [7], PVGIS [6], and Sunny Design [5].

In Sunny Design [5] and PV*SOL [7], the building's location was selected, and the photovoltaic panels were arranged on the roof according to their actual physical layout. After entering the relevant system parameters, the software generated graphs and data on expected energy production. An example of a production forecast graph generated by PV*SOL is shown below:

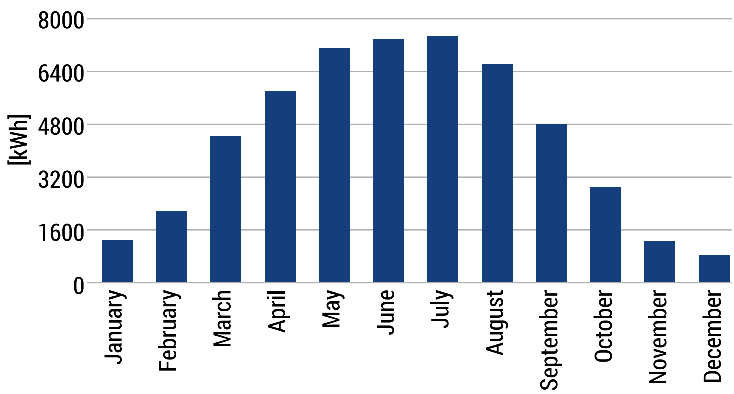


FIGURE 3. Sample forecasted energy production graph generated using PV*SOL [7]

Simulations in PVGIS [6] were based solely on the location and specified system parameters, including azimuth. No panel layout was performed on the building's roof. The production forecasts from PVGIS are illustrated below:

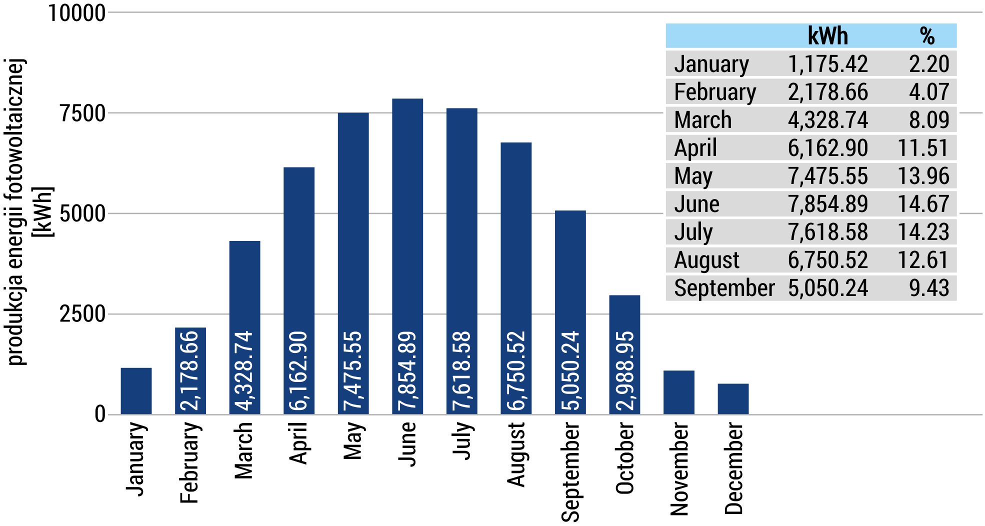


FIGURE 4. Sample forecasted energy production graph generated using PVGIS [6]

After completing all simulations, the following results were obtained:

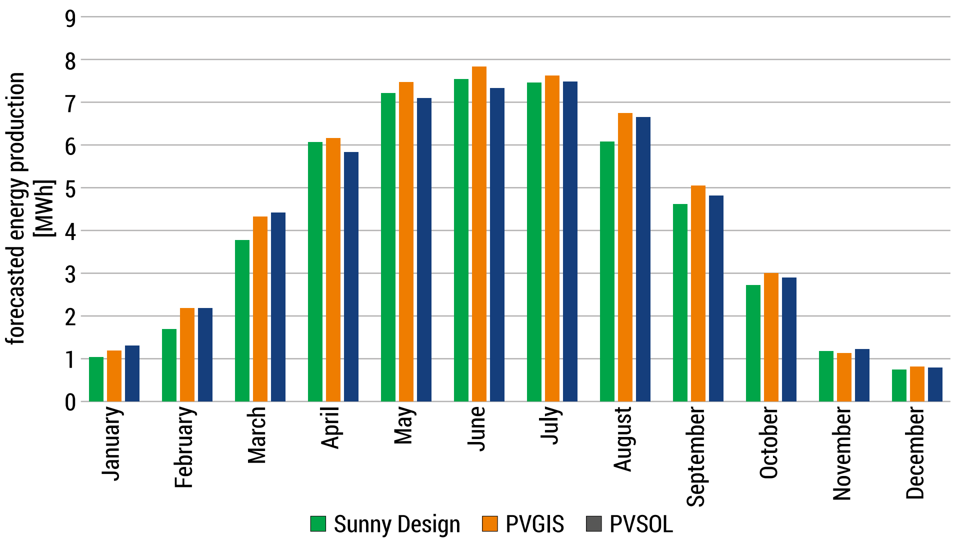


FIGURE 5. Graph presenting forecasted energy yields from the PV installation

TABLE 1. Forecasted energy yield values from selected simulation programs

| Month | Sunny Design [MWh] | PVGIS [MWh] | PVSOL [MWh] |
|---|---|---|---|
| January | 1.033 | 1.1754 | 1.3061 |
| Febuary | 1.682 | 2.1787 | 2.1786 |
| March | 3.766 | 4.3287 | 4.4225 |
| April | 6.063 | 6.1629 | 5.8404 |
| May | 7.2 | 7.4756 | 7.1017 |
| June | 7.53 | 7.8549 | 7.3405 |
| Jul y | 7.462 | 7.6186 | 7.4901 |
| August | 6.085 | 6.7505 | 6.6691 |
| September | 4.615 | 5.0502 | 4.832 |
| October | 2.706 | 2.989 | 2.8985 |
| November | 1.183 | 1.1304 | 1.2363 |
| December | 0.747 | 0.8221 | 0.8095 |
| **Σ** | **50.072** | **53.537** | **52.1253** |

Upon analyzing the forecasted energy yields, it can be observed that Sunny Design generally provides lower monthly values compared to the other two programs. These differences are likely due to each program using a different simulation model – some more advanced than others – and relying on weather data from various meteorological stations.

PVGIS consistently shows the highest forecasted energy yields across most months. These discrepancies may also stem from the fact that Sunny Design and PV*SOL included detailed panel layouts with physical components, whereas PVGIS did not incorporate such spatial modeling. The highest annual energy production is predicted by the simulation performed using PVGIS. The lowest annual energy production is simulated by Sunny Design.

It is important to note that simulation values are based on long-term historical data, and the forecasted energy yield is typically calculated as an average of these values. Given that each of the three simulations provides different energy yield estimates, a key question arises: Which forecast most closely reflects actual energy production?

To answer this, actual energy production data from a PV installation with the same location and parameters used in the simulations was analyzed.

The monthly energy production values for the years 2024 and 2025 were as follows:

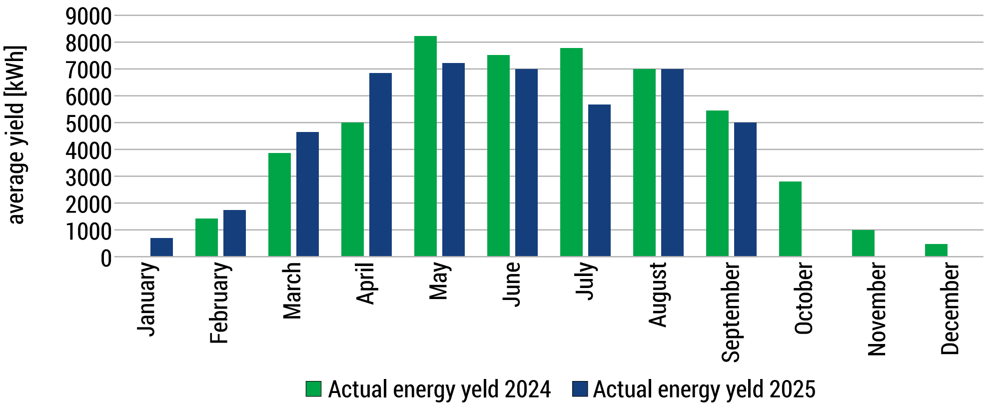


FIGURE 6. **Graph comparing actual energy production**

The graph shows that monthly energy production varies significantly between years. This is due to weather conditions – specifically, the number of sunny days per month – which fluctuate annually. To compare actual results with simulated ones, the average of the real production values was calculated.

The comparison between forecasted and actual average monthly energy production is presented below:

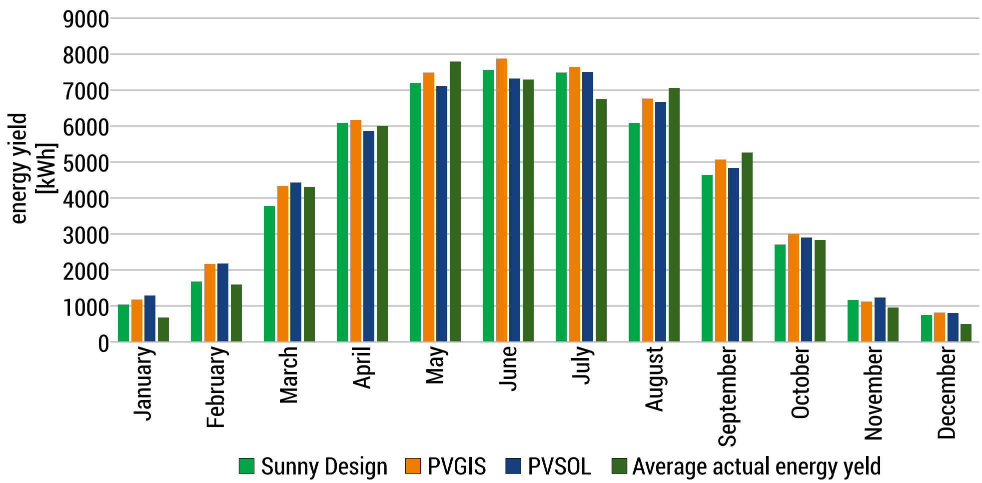


FIGURE 7. **Graph comparing simulated energy yields with average actual production**

Based on the comparative graph and Table 2, it is evident that forecasts for December, January, and February are significantly overestimated by all three programs. Sunny Design consistently shows the lowest forecasted values across most months compared to the other two simulations.

TABLE 2. Comparative table of forecasted energy yields and average actual energy production

| Month | Sunny Design [kWh] | PVGIS [kWh] | PVSOL [kWh] | Average actual energy yield [kWh] |
|---|---|---|---|---|
| January | 1033 | 1175.4 | 1306.1 | 684 |
| Febuary | 1682 | 2178.7 | 2178.6 | 1595 |
| March | 3766 | 4328.7 | 4422.5 | 4305 |
| April | 6063 | 6162.9 | 5840.4 | 5985 |
| May | 7200 | 7475.6 | 7101.7 | 7790 |
| June | 7530 | 7854.9 | 7340.5 | 7280 |
| July | 7462 | 7618.6 | 7490.1 | 6760 |
| August | 6085 | 6750.5 | 6669.1 | 7035 |
| September | 4615 | 5050.2 | 4832 | 5260 |
| October | 2706 | 2989 | 2898.5 | 2820 |
| November | 1183 | 1130.4 | 1236.3 | 969 |
| December | 747 | 822.1 | 809.5 | 494 |
| **Σ** | **50072** | **53537** | **52125.3** | **50977** |

The average annual actual energy production is approximately P = 51,000 kWh. This value is higher than the production forecast generated by Sunny Design, but lower than the production forecast from the other two programs. However, the data does not allow for a definitive conclusion as to which program provides the most accurate forecasts. Each tool offers values close to actual production in some months, while in others the forecasts are either overestimated or underestimated.

To further refine the analysis, the average forecasted energy yield from all three programs was calculated and compared to the average actual production:

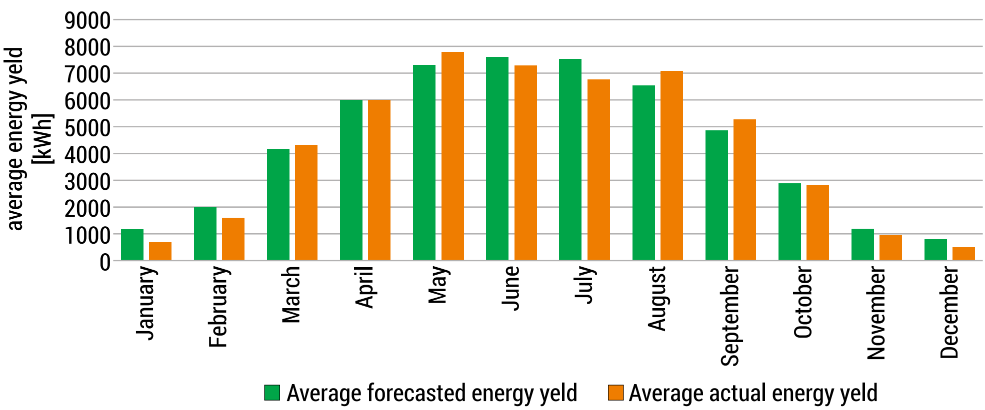


FIGURE 8. Graph comparing average forecasted energy production with average actual production

This graph shows that the average forecasted values are generally closer to actual production. In June and July, as well as from November to February, actual production is slightly lower than forecasted. In other months, actual values are equal to or even exceed the forecasts.

In conclusion, no simulation software provides a perfect model for predicting real-world energy production. Each program uses different weather datasets and simulation algorithms of varying complexity. The most reliable approach is to calculate the average forecast from multiple programs, which yields the most probable and realistic estimate of annual energy production from a PV installation.

## Is It Worth Implementing an Energy Storage System?

As the name suggests, an energy storage system is designed to **accumulate surplus energy** produced by a photovoltaic (PV) installation during its operation, so that it can later be used to power devices connected to the electrical network when the PV system is not generating energy [3]. This solution is particularly beneficial for users seeking greater independence from the public power grid and aiming to reduce electricity purchase costs during periods of high market prices.

### Advantages of Energy Storage [4]

Implementing an energy storage system offers several key benefits:

- Increased energy independence: Users can reduce the risk of power outages by using stored energy to supply critical devices.
- Higher self-consumption: Surplus energy can be used later, increasing the self-consumption rate from approximately 20% (without storage) to 70–80% (with storage).
- Reduced electricity costs: Higher self-consumption directly lowers the amount of energy purchased from the grid.
- Grid support: Sudden spikes in renewable energy generation can overload the grid and cause instability. Storage systems help by absorbing excess energy and releasing it gradually, improving grid stability.
- Smart energy management: Modern energy management systems can intelligently control charging and discharging cycles based on:
  - forecasted building energy demand,
  - predicted weather conditions,
  - market electricity prices.

### Limitations and Considerations [4]

Despite their advantages, energy storage systems also have drawbacks:

- High upfront cost: Batteries and associated infrastructure are expensive.
- Limited lifespan: Storage systems degrade over time and require eventual replacement.
- Energy losses: Charging and discharging processes involve efficiency losses.

- Installation constraints: Finding a suitable location for optimal operation is essential.
- Economic viability: Under net-metering schemes, users can feed energy into the grid and retrieve 70–80% of it free of charge. In such cases, the cost of installing a storage system may outweigh the benefits, making the investment economically unjustified.

### When Is Storage Worthwhile?

The decision to implement energy storage depends on several factors:

- Billing system: Under net-metering, storage may be unprofitable. Under net-billing, it can yield higher returns by allowing users to consume self-generated energy later rather than selling it at fluctuating market prices.
- Consumption profile: If the building's energy demand curve aligns closely with the PV production curve, storage may be unnecessary, unless used for backup power or arbitrage (buying energy at low prices and using it when prices are high).
- Surplus energy levels: If the system generates significant excess energy, storing it can lead to substantial savings and increased self-consumption [4].

## Profitability and Payback Period of the Investment – Simple Payback Analysis

This section analyzes two variants of photovoltaic installations: one with an energy storage system and one without. Both installations are assumed to operate under a net-billing settlement scheme. For each variant, a simple payback period is calculated to compare the time required to recover the investment.

### Variant I – PV Installation with Energy Storage

Assumptions:

- Average annual energy production: approximately P = 50.977 MWh.
- Total investment cost: approximately 240,000 PLN.
- Self-consumption rate: 70%, equivalent to P = 35,683.9 kWh.
- Electricity price: 1.80 PLN/kWh.
- Annu savings: 35,683.9 kWh * 1.80 PLN/kWh = 64,231.02 PLN.

Simple Payback Period (SPP) is calculated as:

$$\text{SPP} = \frac{\text{Investment Cost}}{\text{Annual Energy Savings}} = \frac{240\ 000\ \text{PLN}}{64\ 231{,}02\ \text{PLN/year}} = 3{,}7\ \text{year} \tag{1}$$

Thanks to the use of an energy storage system, which increased the self-consumption rate to 70%, the investment, despite the additional cost of the battery, achieves a relatively short payback period of less than 4 years.

### Variant II – PV Installation without Energy Storage

Assumptions:

- Average annual energy production: approximately P = 50.977 MWh.
- Total investment cost: approximately 150,000 PLN.
- Self-consumption rate: 20%, equivalent to P = 10,195.4 kWh.
- Electricity price: 1.80 PLN/kWh.
- Annual savings: 10,195.4 kWh * 1.80 PLN/kWh = 18,351.72 PLN.

Simple Payback Period (SPP) is calculated as:

$$SPP = \frac{\text{Investment Cost}}{\text{Annual Energy Savings}} = \frac{150\ 000\ \text{PLN}}{10\ 195{,}4\ \text{PLN/year}} = 8{,}2\ \text{year} \tag{1}$$

Without an energy storage system, despite lower initial costs, the payback period is more than twice as long, due to the significantly lower self-consumption rate. Additional revenue could be generated by selling surplus energy to the grid. However, under the net-billing scheme, this is difficult to estimate due to dynamic market prices. During periods of high PV generation, electricity prices may become very low or even negative, and grid voltage may rise to levels that prevent the system from feeding energy into the grid.

## Summary

Based on the analysis of forecasted energy production from various simulation programs, it can be concluded that no single software tool provides a perfect prediction of actual monthly energy yields. This is primarily due to the fact that each program relies on different weather data sources and employs simulation algorithms of varying complexity.

Similarly, actual energy production varies from year to year, even for the same month, and cannot be precisely predicted. Production is influenced by numerous environmental factors, which have a significant impact on the final energy yield.

Energy storage systems, which are gaining popularity, are not universally cost-effective. Therefore, a thorough analysis is required to determine whether their implementation is economically justified in a given scenario.

In the profitability analysis conducted for the PV installation discussed in this study, whose forecasted yields were previously presented, it was shown that, despite the higher initial investment associated with purchasing an energy storage system, the payback period was twice as short compared to a system without storage.

The economic viability of a photovoltaic installation depends on many factors. Consequently, conducting a detailed analysis of forecasted energy production is highly beneficial. It demonstrates that relying solely on data from a single simulation program may lead to significant discrepancies when compared to actual performance.

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