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Analysis of the Impact of the Level of Self-Consumption of Electricity from a Prosumer Photovoltaic Installation on Its Profitability under Different Energy Billing Scenarios in Poland

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Abstract: Renewable Energy Sources (RES) have been gaining popularity on a continuous basis and the current global political situation is only accelerating energy transformation in many countries. Objectives related to environmental protection and use of RES set by different countries all over the world as well as the European Union (EU) are becoming priorities. In Poland, after years of a boom in photovoltaic (PV) installations, the Renewable Energy Sources Act has been amended, resulting in a change to the billing system for electricity produced by individual prosumers. The change in the billing method, also in pursuance to the provisions of EU laws, has contributed to the inhibition of the PV installation market for fear of energy prices and investment payback time. In this paper, by using the Net Present Value (NPV) method, three mechanisms of billing of electricity from prosumer micro-installations—based on the net-metering principle and net-billing principle (using monthly and hourly prices)—have been analysed. Particular attention has also been paid to the aspects of electricity self-consumption and energy storages, which play a significant role in the economy of PV installations in the net-billing system.

Keywords: photovoltaics; NPV; net-billing; net-metering; self-consumption; energy storage

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1. Introduction

The current global economic and political situation related to the events that took place in 2022 has contributed to an acceleration of changes in the use of Renewable Energy Sources in the energy economy of many countries around the world and, in particular, in the countries of the European Union, including Poland. The EU's Fit for 55 legislation package includes a proposal for an amendment to the RES Directive, aimed at raising the current EU target for the use of RES in the overall energy mix from 32% to at least 40% by 2030 [1]. Furthermore, the European Union has committed to drastically reducing greenhouse gas emissions. The goal by 2030 is to reduce these emissions to 55% when compared to levels in 1990, in order to achieve climate neutrality by 2050 [2]. To this end, there is a commitment to review the EU climate and energy policy framework by 2030 with a view to further promotion of energy efficiency and an increase in the share of RES to at least 40%. Additionally, in the face of the energy crisis, a regulation that provides for three remedies has been introduced: a reduction in electricity consumption, the introduction of a revenue cap for electricity producers and the introduction of a solidarity contribution on the fossil fuel sector. EU Member States have committed themselves to reducing electricity consumption by at least 5% during peak demand hours in order to reduce the demand for gas used to produce electricity, and thus, lower its price. The financial gains of the energy sector obtained in this way will be passed on to the most vulnerable people and companies in the EU struggling to pay their bills. These provisions are exceptional and temporary, and will apply from 1 December 2022 to 31 December 2023 [3].

In the situation that has arisen, individual EU member states are creating their own programmes aimed at achieving common EU RES targets. In recent years, Poland has seen a very rapid increase in the number of prosumer PV micro-installations following the introduction of the RES Act in 2015. At the end of August 2022, the total capacity of PV plants connected to the electricity grid in Poland was more than 11 GW, of which as much as 75% (8.26 GW) were low-power prosumer installations. The year-on-year increase was as high as 84.3%, and the average capacity of a new PV installation was approximately 14 kW. Poland was ranked 10th in the world in terms of investment in new PV generation capacity realised in 2021, according to the ranking published by the Solar Power association. All generation sources in Poland have a capacity of approximately 59.02 GW and the share of RES is as much as 35.4% (20.9 GW), of which more than 53% is covered by PV, and 37% by wind power [4,5]. Thanks to support programmes, such as My Electricity for individual users, in mid-2022, Poland met the targets regarding the installed capacity in RES set for itself by 2040. The large capacities of PV installations, which are characterised by instability of production, in addition to their advantages, also brought a number of negative issues, such as excessive values of momentary power in the power system, PV inverters shutting down during periods of high power generation, etc. Therefore, there was an amendment to the RES Act in 2022, which changed the system for billing energy from prosumer installations from net-metering to net-billing, which has definitely slowed down the process of development of new PV installations. The Polish legislator justified the change of regulations, inter alia, the need to implement the provisions of Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market in electricity and amending Directive 2012/27/EU.

There are a number of publications where the authors analyse the energy potential of selected regions of the world with regard to the use of PV systems using various software packages (e.g., PV SOL, PVsyst, PV GIS). Such studies have been conducted, for example, in an area covering five provinces in China [6], with the achievement of approximately 20% of the energy demand of the facilities, using only the roofs of single-family houses, while maintaining positive economic indicators. Similar analyses, using the Polysun software, were carried out for the area of Jordan, given the country’s diverse climatic zones [7], which demonstrated a degree of satisfaction for electricity from PV systems of almost 30% over the 25-year life of the installation. In addition to economic and energy gains, the use of PV systems will contribute to a reduction of CO2 emissions whilst aiding climate protection. For the areas of Greece and Turkey, high NPV ratios for PV systems were also reported, and attention was drawn to the particular dependence of the actual energy yields of the installations analysed compared to the results obtained from simulations in the PVsyst and PVGIS software, which were overestimated [8]. The mounting of PV installations on water, as shown in an analysis carried out for Polish climatic conditions [9], has not brought positive economic indicators, making these systems less profitable than systems mounted on the ground or on buildings. The lack of profitability of these systems is influenced by the higher costs of the supporting systems and the electrical connection systems of the installation. Additionally, if there is a need to upgrade the station of the power system to which the new high-power PV systems are planned to be connected, the NPV of the investment may be negative [10]. There are many works [11–14] where the authors have performed experimental and simulation studies of photovoltaic systems operating in different climatic conditions, based on various types of PV cells (polycrystalline, monocrystalline, organic, and others), and as a result, it affects changes in their output parameters and energy yields, which is important in later economic analyses. Additionally, in terms of obtaining accurate values of NPV or LCOE indicators, is the selection of the load profile of the analysed object [15], where various methods can be used. Averaged values for longer time periods can be assumed if it is not important to determine specific indicator values but to show general trends in their changes, or more precise profiles, such as those for the United States [16] or for household in Germany [17], can be used. The methodology for predicting loads in Europe using artificial neural networks is described in [18].

Net-billing and net-metering systems are used and analysed in many papers, such as [19], where the authors, based on the example of systems present in Spain, pointed out the necessary legal changes in other countries (e.g., Ecuador) to increase the profitability of PV installations there. The application of NPV or LCOE methods shows the validity and profitability of investments in PV systems in different regions of the world, whether in stationary systems, solar trackers, or the use of bifacial panels [20–25]. The authors of [26] pointed out in their analyses the significant impact of energy self-consumption and government subsidy levels on the NPV ratio and payback time of high-power PV systems in Italy, with billing mechanisms for energy sold at an annual price. On top of this, PV system designs are characterised by low coefficients of variation and low investment risk, with high NPV and profitability indexes (PI) [27], and are particularly cost-effective in areas with high current demand, such as farms [28]. The power of the PV micro-installation is also important for changing the NPV, depending on whether the system is designed to supply 100% of the energy for the house in the first or last year of the system's operation [29].

A way to improve the economic indicators of PV installations is to use energy storages for the Feed in Tariff (FiT) system using algorithms that optimise the energy flows in the electrical system, as demonstrated in an office building in Beijing [30]. It was pointed out that the most important parameter affecting the economics of the installation is the price of electricity. Economic analyses were also conducted for PV systems connected to storage systems in China. For the five different scenarios of operation of these systems under analysis, a payback period of 8–17 years was achieved and a particularly important achievement is the demonstration of the superiority of using the next day's weather forecast in the energy storage algorithms, when compared to using the weather data from the previous day [31]. Another important consideration is the coupling of the FiT system with the current energy use in educational facilities in China (due to specific energy consumption periods), as has been pointed out in [32]. Appropriate optimisation of consumption and energy production in combination with active government support makes the achievement of a financial payback period of several years (about 6 years) possible. Additionally, in Italy, high NPVs have been obtained for PV installations when high government subsidy rates are applied to newly built systems [33]. When analysing, using the LCOE method, the situations in all EU countries, as well as Norway and Sweden, with regards to the use of building-integrated PV systems (BIPV) in densely built-up residential areas, it was found that these systems were profitable if the electricity sale price was equal to the price of its purchase [34].

In many countries, not only European ones, there are similar ways of billing electricity from photovoltaic installations to those existing in Poland, but despite the similarities in the overall scope, there are minor differences that point to discrepancies between the countries. Thus far, the net-billing system has been based on electricity prices for longer periods (e.g., monthly, such as the analyses presented in the paper [35]), and there are no analyses of short-term prices, e.g., daily or hourly prices. The analysis of the profitability and NPV of PV farms in Poland always shows positive values of the ratios [36] for the use of annual electricity sales prices. In consideration of the above, the authors of this paper have made an attempt to indicate the changes in the profitability of low-power PV installations for different variants of energy billing, along with an indication of the significance of the level of self-consumption and self-storage of electricity for each of the billing methods, with particular consideration of hourly electricity sales prices. The main goal is to show the significance of the impact of the level of self-consumption and energy storage from low-power prosumer RES installations, especially with short-term energy settlement prices, and not to achieve specific values of economic indicators that will be affected by the load profile of the household and production energy.

2. Legal Conditions and Billing Systems for Electricity from Prosumer Installations in Poland

2.1. Legal Information

2.1.1. Definition of a Prosumer

The definition of a prosumer in Poland was introduced in the Act of 22 June 2016 on amending the renewable energy sources act and certain other acts. It identifies a person or entity that is the end recipient producing electricity using renewable energy sources to cover their own energy needs, with the nominal power of generation sources not exceeding 50 kW (e.g., micro-installations) [37].

An example of a prosumer installation could be a photovoltaic (PV) system working with a low-voltage power grid. It is possible to distinguish three main modes of PV installations in Poland [38–40]:

- On-grid—a system connected to the power grid;
- Off-grid—a system not connected to the power grid (stand-alone/island installation), which requires storage of the electricity produced in a local storage facility;
- Hybrydowy—a system connected to the power grid equipped with a charge controller and local energy storage.

The vast majority of the photovoltaic installations put in place in Poland belong to the group of grid-connected (on-grid) systems. This is influenced, among other things, by the high price of electricity storage and the attractive billing system for the energy produced, so-called net-metering, which has been in place until now.

In connection with the choice of a system that works with the power grid, it was necessary to draw up legislation that would determine the way in which the electricity supplied to the grid from a photovoltaic installation was to be billed. On 1 July 2016, a billing system for electricity produced in the so-called "discount system" was put in place in Poland. However, on 1 April 2022, this system was replaced by the so-called net-billing system. The change in the applicable electricity billing system caused stagnation in the market for new PV installations due to concerns regarding the investment payback time.

2.1.2. Discount System

A discount system, otherwise known as net-metering, is a billing system which concerns the amount of electricity fed into the power grid. In this case, the grid is treated as a virtual energy storage. This means that surplus electricity produced can be sent to the Distribution System Operator (DSO) and collected when the photovoltaic installation supplies too little or none at all (e.g., at night). The use of the option to store the surplus electricity is associated with the following losses in the case of [41–43]:

- Installations with an installed capacity of up to 10 kW—at a ratio of 1 to 0.8;
- Installations with an installed capacity equal to and above 10 kW—at a ratio of 1 to 0.7.

In practice, this means that for every 1 kWh of electricity introduced into the power grid, it will be possible to collect 0.8 kWh or 0.7 kWh within a year of its introduction. The remaining electricity remains at the disposal of the distribution system operator [42,43].

The discount system has been commented on unfavourably by distribution system operators as well as electricity suppliers. The problem that these institutions pointed out was, among other things, that the energy introduced into the grid by the prosumer was exempt from distribution charges despite generating network variable costs. Furthermore, it is worth pointing out that the connection of the micro-installation to the power grid is free and the operator must not charge any remuneration for it. On the other hand, it must also be indicated that, as part of energy storage, 20% or 30% of the energy introduced into the grid was deducted from the prosumer, respectively. However, according to the retailers belonging to the Association of Energy Trading, the assumed discount factors were too low to cover the variable distribution costs generated. It was estimated that the financial losses could be as high as several million PLN per year [44]. However, the prosumer, when taking a decision related to the purchase of a PV system, only took into account their own financial savings resulting from the PV installation, without paying attention to the DSO's costs.

Those wishing to rely on net-metering for the next 15 years had to notify the DSO of the micro-installation connection by 31 March 2022. However, the grid operator leaves the option of voluntary transition to the new billing system to each prosumer [45]. Additionally, an incentive in the form of a subsidy for photovoltaic installation from the government programme My Electricity 4.0 is to be used for this purpose. On 15 April 2022, the National Fund for Environmental Protection and Water Management launched a call for applications for the subsidy. However, it only addresses prosumers using the new net-billing system. The amount of the subsidy for the photovoltaic system alone is in turn PLN 4000, or PLN 5000 if the investor decides to additionally purchase an electricity or heat storage. On the other hand, if a prosumer who has used the net-metering system so far decides to switch to the new billing system and has previously received a subsidy for the micro-installation, they have the possibility to benefit from additional financial support for the photovoltaic system in the amount of PLN 2000 [46].

2.1.3. Net-Billing System

The new billing system consisting of the value-based settlement of surplus electricity involves the separate settlement of energy supplied into the grid and energy taken from it using the value of energy determined according to the exchange price. It became effective in Poland on 1 April 2022. This means that the prosumer will receive the market price for the electricity supplied into the grid produced from his or her own photovoltaic installation. On the other hand, they will pay the same price for energy taken from the grid as a consumer without a micro-installation [47].

The introduction of changes in the electricity billing method for prosumers is supposed to ensure greater integration of RES into the national power system and increase its flexibility and energy efficiency. Additionally, the investor is an active participant in the energy market, thus gaining greater awareness of the rules of the market, which in turn is expected to motivate them to manage and store energy prudently [48].

Even long before the new billing system was introduced, it was met with a very sceptical reception. Many people inside and outside the photovoltaic industry expressed very negative opinions about net-billing. It is worth pointing out that Polish society has become accustomed to the previous system of discounts, which can be noticed when observing the development of photovoltaics in the recent years. However, the system introduced in our country is already in place in Italy, Mexico, the United States, and Portugal, to name but a few [48].

The period of introduction of the net-billing system has been divided into the following stages [37,48]:

- Transitional discount system (from 1 April 2022 to 30 June 2022)—in effect for prosumers who reported the connection of the micro-installation to the DSO in the abovementioned period. However, after the transitional period, the surplus electricity supplied into the grid was billed at the average monthly price valid in June 2022, and investors automatically started to be net-billed.
- Net-billing based on monthly prices (from 1 July 2022 to 30 June 2024)—during this two-year period, surplus electricity introduced into the grid will be billed based on the average market price for electricity that applied in the previous month.
- Net-billing based on hourly prices (from 1 July 2024)—eventually, the billing of the value of surplus electricity will be based on the application of dynamic tariffs based on hourly prices and a distinction between electricity introduced into the grid and electricity consumed. The introduced energy will be billed on the basis of the hourly exchange price in the day-ahead markets. It will be determined by the energy

information market operator, i.e., Polskie Sieci Elektroenergetyczne (Polish Transmission System Operator). On the other hand, the value of electricity consumed will depend on the tariff of the current supplier.

The aim of the net-billing system is to encourage self-consumption, i.e., the use of generated electricity for the current energy needs of a household. It is intended to encourage investors to purchase energy storages, so that when there is too much energy generated from the photovoltaic installation, it is not sent to the power grid but to a private battery. This will allow for savings on distribution charges collected by the operator and will increase the prosumer's energy independence without overloading the power system [41].

Next, net-billing is intended to draw attention to the prudent sizing of PV installations. The phenomenon of oversizing micro-installations was very common in the case of the discount system. The investor often opted for a photovoltaic system that was about 20–30% larger in order to compensate for the amount of energy introduced into the grid, which remained available to the operator there. The change in the billing system will have an impact on the design of smaller installations, allowing them to be used more efficiently and reducing the investment payback time through lower initial costs [48].

2.2. Design of the Prosumer Photovoltaic Installation

In order to demonstrate the differences in the investment payback time for a prosumer photovoltaic installation, the design of such an installation was carried out on the basis of the assumptions made.

The residential building for which the PV installation was designed is located in central Poland (in Bydgoszcz, Kuyavian-Pomeranian Province). A family of four living there consumes, on average, 4500 kWh of electricity per year. The PV installation was designed to be mounted on a south-east facing roof (azimuth 160°) and inclined at 30°. The climatic data for the selected location were determined in the PV SOL Premium 2022 software (test version) and their values are as follows:

- Annual total insolation: 1053 kWh/m^2;
- Annual average temperature: 8.7 °C.

The power of the designed photovoltaic installation was determined on the basis of the following equation [49]:

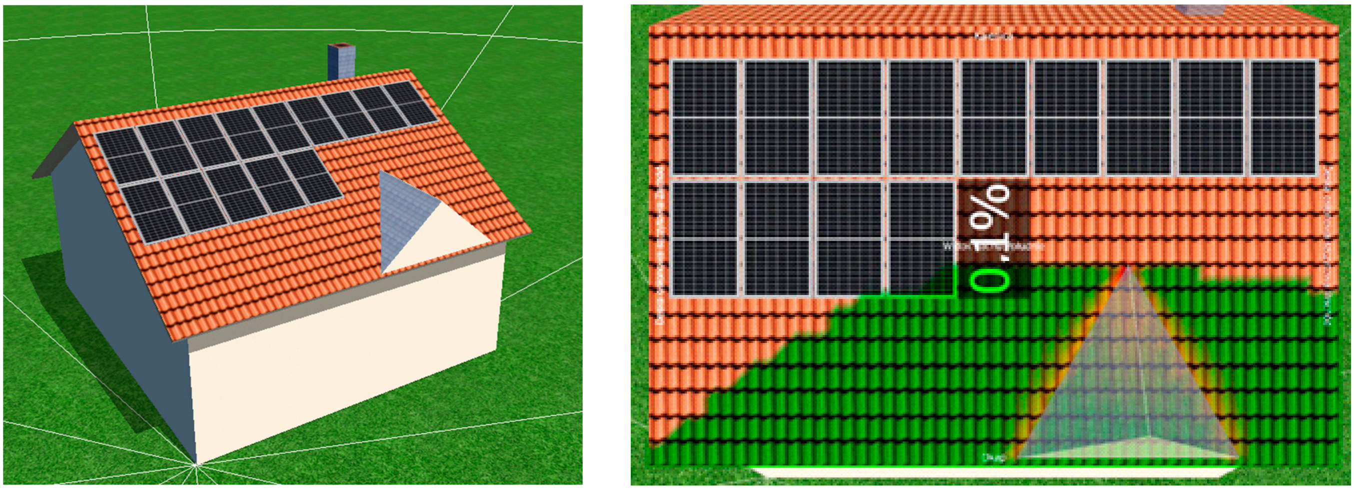
$$P_{PV} = \frac{E_k}{E_p} = \frac{E_k}{\frac{N}{G_{STC}} \cdot w_w \cdot w_{kn}} = \frac{4500\ kWh}{\frac{1053\ kWh/m^2}{1kW/m^2} \cdot 0.8 \cdot 1.12} \approx 4.77\ kW \quad (1)$$

where:

P_{PV}—power of the photovoltaic installation [kW];
E_k—annual electricity consumption [kWh];
E_p—yield, annual production of electricity from 1 kW of power installed in the photovoltaic system [kWh];
N—insolation falling on a given area during the year [kWh/m^2]; for Poland, this value is between 975 and 1150 kWh/m^2 depending on the exact location [50];
G_{STC}—power density of solar radiation in STC = 1000 W/m^2;
w_w—coefficient of performance; usually, its value ranges between 80 and 85%, and is influenced by the following losses: on wires, on modules due to temperature, inverter losses, and others;
w_{kn}—insolation correction factor, which depends on the angle of inclination of the photovoltaic system and its azimuth; a table with all the data can be found in [49] on page 199.

The cost-effectiveness analysis for the designed photovoltaic installation will be determined for both net-metering and net-billing systems. The former recommends oversizing the installation by 20% for a system capacity up to 10 kW. On the other hand, when energy is billed using the net-billing system, the value of the designated photovoltaic system capacity should remain unchanged. However, in this case, when the system will be considered in both cases, an oversizing of the photovoltaic installation by 10% is assumed; hence, the value of the installed capacity should be 5.25 kW. The rated power of the designed installation was set at 5.25 kW, which should generate 5621 kWh of energy in the first year of operation (according to the simulation results in the PV SOL program).

The designed photovoltaic system was modelled using the PV SOL Premium 2022 software. Figure 1a shows the distribution of the photovoltaic panels on the roof slope of a single-family house, while Figure 1b presents an analysis of the incidence of shadows, which does not occur in this case. A wiring diagram of the PV installation connected to the domestic wiring system is shown in Figure A1 in Appendix A.



(a) (b)

Figure 1. Visualisation of the PV installation on the roof of the building: (**a**) arrangement of panels, (**b**) analysis of the incidence of shadowing on PV modules.

Table 1 shows the costs of the components that make up the designed PV installation, which will be necessary to perform further economic analyses. Local price lists from companies operating in the photovoltaic industry have been used. The cost of the assembly structure was assumed to be 8% of the cost of all equipment, while the assembly service for the photovoltaic system was determined as 15% of the total cost [49]. The prices in the table are gross prices in PLN.

Table 1. Cost estimate for the designed photovoltaic system.

No.	Name of Device	Quantity	Unit Price [PLN/Unit]	Total Price [PLN]
1.	JA SOLAR JAM60S20-380/MR photovoltaic panel	14	849.00	11,886.00
2.	FRONIUS SYMO HYBRID 5.0-3-S inverter	1	4649.00	4649.00
3.	DC H1Z2Z2-K cable 1 × 4 mm^2	20 m	20.50	410.00
4.	AC H07RN-F cable 5 × 2.5 mm^2	5 m	8.40	42.00
5.	HAGER SB432PV DC switch-disconnector	1	179.00	179.00
6.	2600 V DC PHOENIX CONTACT low voltage surge arrester	2	725.00	1450.00
7.	2 AC VCX-L1-4 class T2 4P low voltage surge arrester	1	138.00	138.00
8.	EATON FAZ-C8/3 8A overcurrent circuit breaker	1	295.00	295.00
9.	Assembly structure for ceramic roof tiles (including rails, clamps)	1	1525.00	1525.00

10.	Assembly service	1	3086.00	3086.00
			SUM	23,660.00

The total cost of the photovoltaic installation including assembly is PLN 23,660. Knowing the sub-assemblies used in the system and the cost of the investment, it is possible to consider its profitability when considering several electricity billing scenarios. In addition to this, the end result will be influenced by factors such as the predicted increase in electricity prices, the lifespan of the system, the decrease in its efficiency over time, the planned replacement of faulty equipment, operational costs, and the changes in the value of money over time.

3. Profitability Analysis of a Prosumer PV Installation under Different Electricity Billing Scenarios

The main factor that will be considered when determining the profitability of a PV installation is the billing scenario for the electricity produced. Three different variants will be considered, in which the profitability of the designed installation will be analysed using:

- The net-metering system (otherwise known as the discount system);
- The net-billing system based on monthly prices;
- The net-billing system based on hourly prices.

In order to perform an economic assessment of the installation, the volume of electricity produced by the designed system and the proportion of energy that will be sent to the power grid, in each year of the projected lifespan of the investment, will be determined.

3.1. Production of Electricity from the Designed Photovoltaic System

On the basis of the simulation carried out in the PV SOL premium 2022 software (test version), the value of the annual insolation at the given location was determined at a level of 1053 kWh/m^2, as shown in Figure 2 on a monthly basis over the course of a year.

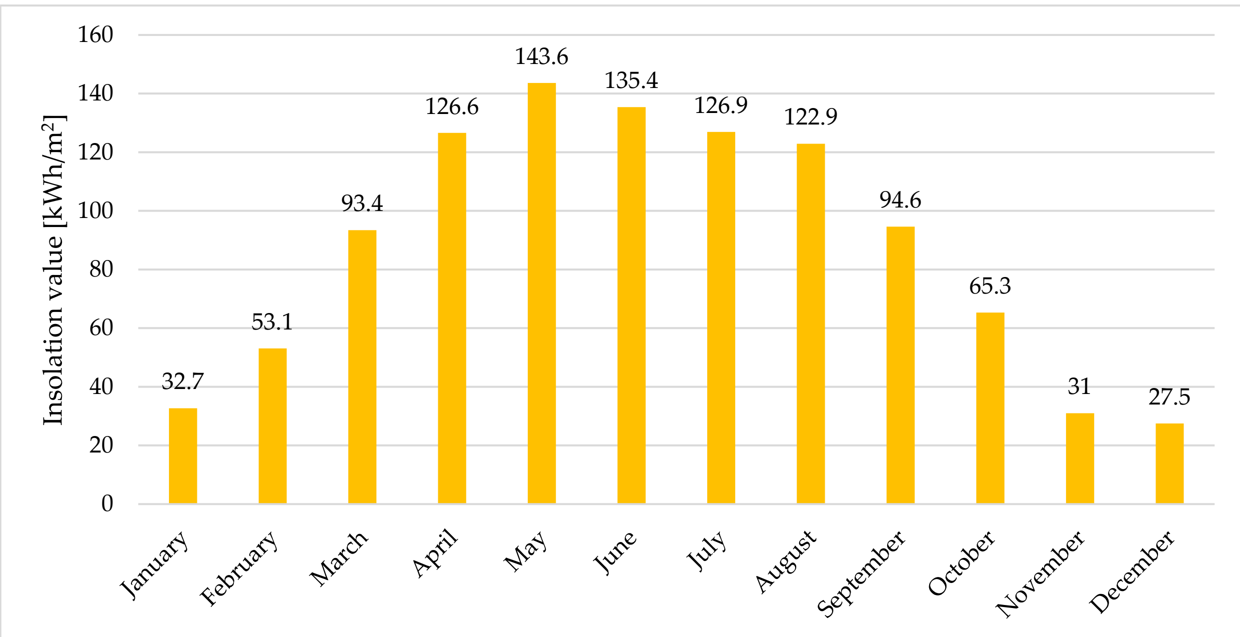


Figure 2. Distribution of insolation over the year for the indicated location.

Based on the abovementioned data and knowledge of the components of which the designed photovoltaic installation consists, the potential electricity production was determined. In order to make the data presented as accurate as possible and to determine the quantity of energy produced from the photovoltaic installation correctly, the decision was taken to use two sources: the PV SOL design software and the Global Solar Atlas website [50]. In each of the sources, the data of the designed photovoltaic installation, such as the power of the system, the manufacturer and model of the equipment used, the angle of inclination of the panels, the azimuth, etc., were entered into the forms. Having analysed the results obtained from PV SOL and Global Solar Atlas, the arithmetic mean value of the electricity produced for each month from these programmes was determined. The predicted annual production of electricity from the photovoltaic installation is 5621 kWh, as shown in Figure 3 by month.

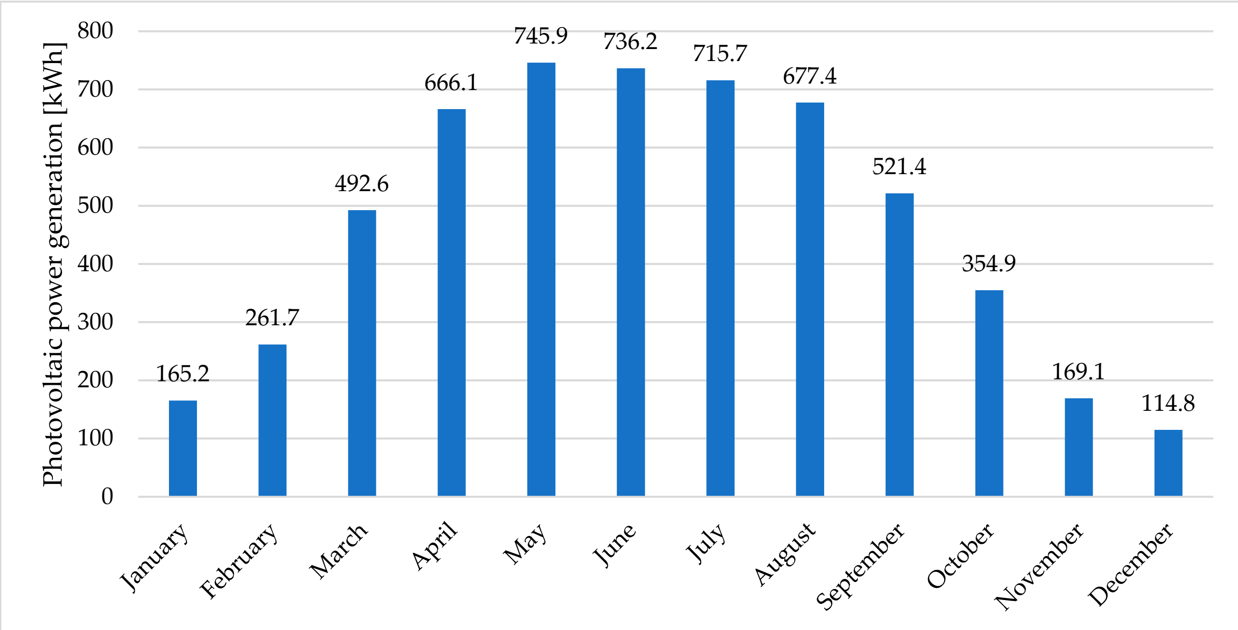


Figure 3. Distribution of the arithmetic mean annual production of electricity from the designed PV system for the indicated location based on data presented in the PV SOL software and on the Global Solar Atlas website [42].

The determined productivity of the PV installation refers to its first year of operation. Given that PV systems are designed for an approximately 25-year lifetime, it was assumed, according to the data sheet of the selected PV panels, that the annual decrease in their efficiency is 0.55% over a 25-year period.

Based on a review of available sources and own observations, a household self-consumption of 30% was assumed, meaning that this amount of electricity would be consumed for the investors' current energy needs and would not be transmitted to the distribution system operator.

According to the assumptions mentioned above, it is possible to estimate the production from the designed photovoltaic installation throughout the lifetime of the system, including the portion of energy intended to cover the current needs of the household. All data have been collected and listed in Table 2.

Table 2. Calculation results of electricity production from the designed photovoltaic installation.

System Operation Period [year]	Decrease in Efficiency of the PV Installation [%/Year]	Production of Electricity from the PV Installation [kWh/Year]	Household Self-Consumption of Electricity [%/Year]	Electricity Used for Investors' Current Needs [kWh/Year]	Electricity Transmitted to the DSO [kWh/Year]
1	0	5621.00	30	1686.30	3934.70
2	0.55	5590.08	30	1677.03	3913.06
3	1.10	5559.34	30	1667.80	3891.54
4	1.65	5528.76	30	1658.63	3870.13
5	2.20	5498.35	30	1649.51	3848.85
6	2.75	5468.11	30	1640.43	3827.68
7	3.30	5438.04	30	1631.41	3806.63
8	3.85	5408.13	30	1622.44	3785.69
9	4.40	5378.38	30	1613.52	3764.87
10	4.95	5348.80	30	1604.64	3744.16
11	5.50	5319.39	30	1595.82	3723.57
12	6.05	5290.13	30	1587.04	3703.09
13	6.60	5261.03	30	1578.31	3682.72
14	7.15	5232.10	30	1569.63	3662.47
15	7.70	5203.32	30	1561.00	3642.32
16	8.25	5174.70	30	1552.41	3622.29
17	8.80	5146.24	30	1543.87	3602.37
18	9.35	5117.94	30	1535.38	3582.56
19	9.90	5089.79	30	1526.94	3562.85
20	10.45	5061.79	30	1518.54	3543.26
21	11.00	5033.96	30	1510.19	3523.77
22	11.55	5006.27	30	1501.88	3504.39
23	12.10	4978.73	30	1493.62	3485.11
24	12.65	4951.35	30	1485.41	3465.95
25	13.20	4924.12	30	1477.24	3446.88

The performance of the abovementioned calculations has made it possible to identify the values of electricity that will be consumed on an ongoing basis throughout the life of the system and transmitted to the distribution system operator, and on the basis of these values, it will be possible to perform various economic scenarios for the installation in question.

3.2. NPV Indicator to Assess the Profitability of the Investment

To create an economic analysis of the investment, one of the discounted profitability assessment indicators will be used, which is the NPV (Net Present Value). The NPV is one of the methods that take into account all costs incurred, i.e., investment and operating costs, but additionally, it takes into account the benefits that the investment under consideration brings, such as proceeds from the sale of, e.g., generated electricity. In the case of the net-metering system, the financial benefits will primarily lie in the fact that the investor does not buy electricity from the seller but produces it and uses it for his own needs. The next section of the paper, on the other hand, will address the net-billing system, which is based on the active sale of the electricity generated. The net present value uses the discount rate r, which determines the variability of the value of money over time. The calculation according to the NPV discount rate is performed by applying the following equation [51,52]:

$$NPV = \sum_{t=0}^{T} \frac{S_t - M_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{I_t}{(1+r)^t} \quad (2)$$

where:

T—predicted lifespan of the investment (25 years according to an assumption);

t—year of the life of the investment;
S_t—savings that occurred in year t due to, for example, the sale of the electricity produced, which are calculated as the product of the electricity that was generated in a given year and the price of electricity that was applicable in year t; in the case of the discount system, these will be the savings resulting from not buying electricity from the operator;
M_t—operational costs in year t;
r—discount rate (assumed value 0.08);
I_t—capital expenditure in year t.

Based on the NPV presented, economic analyses of the designed prosumer PV installation will be conducted for different billing systems, at different levels of energy self-consumption.

3.3. Electricity Billing under the Discount System

The installed capacity of the designed PV installation is 5.32 kW, which means that for every kilowatt hour fed into the power grid, the operator will take 0.2 kWh, while the remaining 0.8 kWh can be collected by the investor at any time for exactly one year from the moment the energy is fed into the grid. For this reason, the discount system, as opposed to net-billing, can be considered on an annual basis. The assumption was made that the household would take all the electricity it needed from the grid operator to cover its current energy needs. Any excess electricity produced will be lost and the shortfall will be purchased at the electricity price prevailing in a given year.

When considering all three cases of billing the electricity produced, an assumption was made that the subsidy for the photovoltaic installation from the government's My Current programme would be equal and amount to PLN 4000 for each system. This measure is intended to compensate for the initial capital expenditure, which will amount to PLN 19,660 in each of the variants.

The cost of electricity in the year in which the photovoltaic installation starts to be used was set at 0.7 PLN/kWh and an annual increase of 2% was assumed. On the other hand, operational costs were assumed at 450 PLN/year. These take into account, among other things, inspections of the photovoltaic installation, replacement of a given sub-assembly in case of damage, and others.

Table A1 provides a detailed profitability analysis of the designed photovoltaic installation using the electricity billing system based on net-metering. Figure 4 shows the change in cash flow of the investment versus its lifetime. The year in which the cash flow value is positive is the year in which the return on investment will take place if the assumptions are met. In the case under consideration, this is the tenth year.

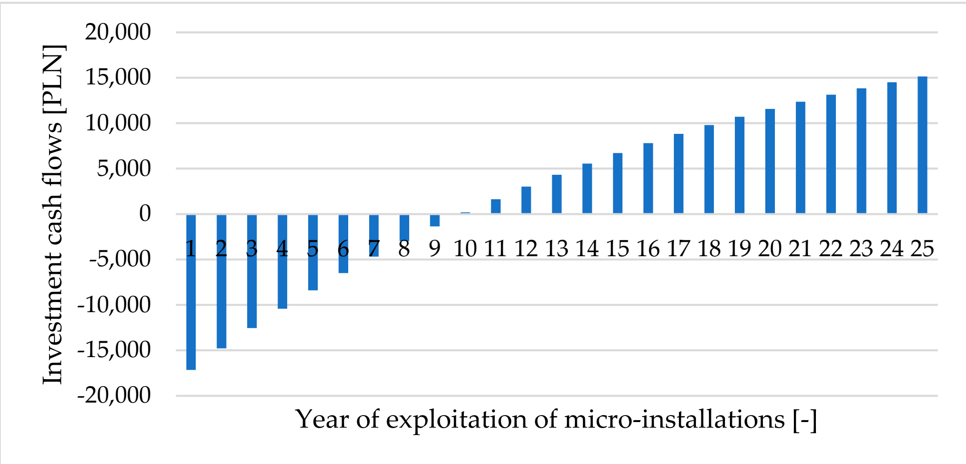


Figure 4. Graph showing the payback period for the capital expenditures incurred in relation to the net-metering system and the 30% self-consumption level.

When analysing the data in Table A1 and Figure 4, it can be seen that the payback time is nine years. In year ten, the designed photovoltaic system will provide the first real financial benefits, which will increase with each year of use of the micro-installation. The profits would be even higher if the surplus electricity produced that was not used by the household was not lost and could be sold to the operator at least for a fraction of its value. Additionally, it should be emphasised that in the 25th year of the system's operation, the projected profits amount to PLN 15,135.20, which means that the investment costs initially incurred have been almost doubled.

3.4. Electricity Billing in the Net-Billing System Based on Monthly Prices

Another system for billing the electricity produced from the micro-installation is net-billing based on monthly prices. This is a system that will be applicable in Poland from 1 July 2022 to 30 June 2024; however, its application during the whole lifetime of the photovoltaic installation has been analysed in the conducted analysis.

The net-billing system consists of active sales and purchases of electricity. The sales of electricity generated, which will not be used for own energy needs and fed into the power grid, will be billed on the basis of the average market price for electricity that applied in the previous month. When comparing this system with the previous one, it should be noted that the creation of an economic profitability analysis on an annual basis will be insufficient in this case.

In the first step of the preparation of the economic analysis, an estimation was made as to the percentage of the total annual electricity production in a given month. The data in Figure 3 were used for this purpose and the results are included in Table 3.

Table 3. Percentage of electricity produced on an annual basis from a designed photovoltaic installation using data from the PV SOL software and the Global Solar Atlas website [50].

Month	Percentage of Electricity Produced from a PV Installation over the Year [%]
January	2.94
February	4.66
March	8.76
April	11.85
May	13.27
June	13.10
July	12.73
August	12.05
September	9.28
October	6.31
November	3.01
December	2.04

Knowing the ratio of energy generated from the PV installation in a given month to the total annual electricity production expressed as a percentage will allow the monthly values of electricity produced from the PV installation, expressed in [kWh/year], to be allocated.

The annual demand of a household for electricity was assumed to be 4500 kWh. It was assumed that this is at the same level each month, due to the fact that in autumn and winter, more time is spent at home, more electronic devices of various types are used and the lighting has to remain on for most of the day. In spring and summer, on the other hand, appliances that consume significant amounts of electricity, such as air conditioners, are used. Therefore, the monthly consumption of electricity by a household was assumed at 375 kWh.

By using a calculation sheet, a table divided into 25 areas was created, each relating to a given year of operation of the system. The areas included columns in which the following values were determined:

- Electricity production for each month, taking into account the percentage electricity production determined in Table 3;
- Household self-consumption at a level of 30% of the electricity produced in each of the twelve months;
- The volume of electricity to be purchased and the amount of money to be paid for it;
- The volume of electricity that will be sold and the amount that investors will receive;
- The amount that will be saved as a result of the production of electricity from the micro-installation for own use.

The sale of unused electricity from the photovoltaic installation will be settled on the basis of the average market price for energy. These data were collected using information from the website of *Polskie Sieci Elektroenergetyczne* (Polish Transmission System Operator) (RCEm—market price of electricity—monthly) and reports from 2021, available on the website of *Towarowa Giełda Energii* (TGE) (Polish Power Exchange) [53]. An increase in the sales price of unused electricity of 2% per year was assumed. The determined amounts of electricity sales in the first year of operation of the micro-installation are shown in Table 4.

Table 4. Monthly sales prices for the electricity produced from the photovoltaic installation in the first year of the system's operation [53].

Month	Electricity Sales Price in the First Year of Operation [PLN/MWh]	Electricity Sales Price in the First Year of Operation—Rounded Values [PLN/kWh]
January	666.90	0.67
February	525.89	0.53
March	683.59	0.68
April	584.45	0.58
May	662.40	0.66
June	659.29	0.66
July	799.79	0.80
August	1023.42	1.02
September	711.92	0.71
October	467.12	0.47
November	552.40	0.55
December	829.98	0.83

In order to carry out an economic analysis, it is necessary to determine the value of the savings that will be generated over the course of the investment. In the case of the net-billing system, this is the sum of the amount received for selling unused electricity and the money saved through self-consumption amounting to 30% of the total electricity production. However, the costs incurred for the purchase of electricity when its production from the micro-installation is too low must be deducted from this value.

The remaining data used to determine the profitability of the system are the same as in the case of the discount system, described in Section 3.3. Table A2 contains the total profitability analysis of the designed PV installation using the net-billing system for electricity based on monthly prices. Figure 5 shows the change in cash flows of the micro-installation versus its lifetime for billing performed on the basis of electricity sales at monthly prices for a 30% self-consumption level. Observing the graph, it can be found that over the lifetime of the photovoltaic system, the investment cash flow value will not be positive. This means that the capital expenditure will not be recouped when the established assumptions are fulfilled (there is still an amount of approximately PLN 2600 left). Thus, the presented billing system is not beneficial for prosumers with the assumed system costs, energy prices, and, above all, the standard low (30%) level of self-consumption of electricity from PV installations.

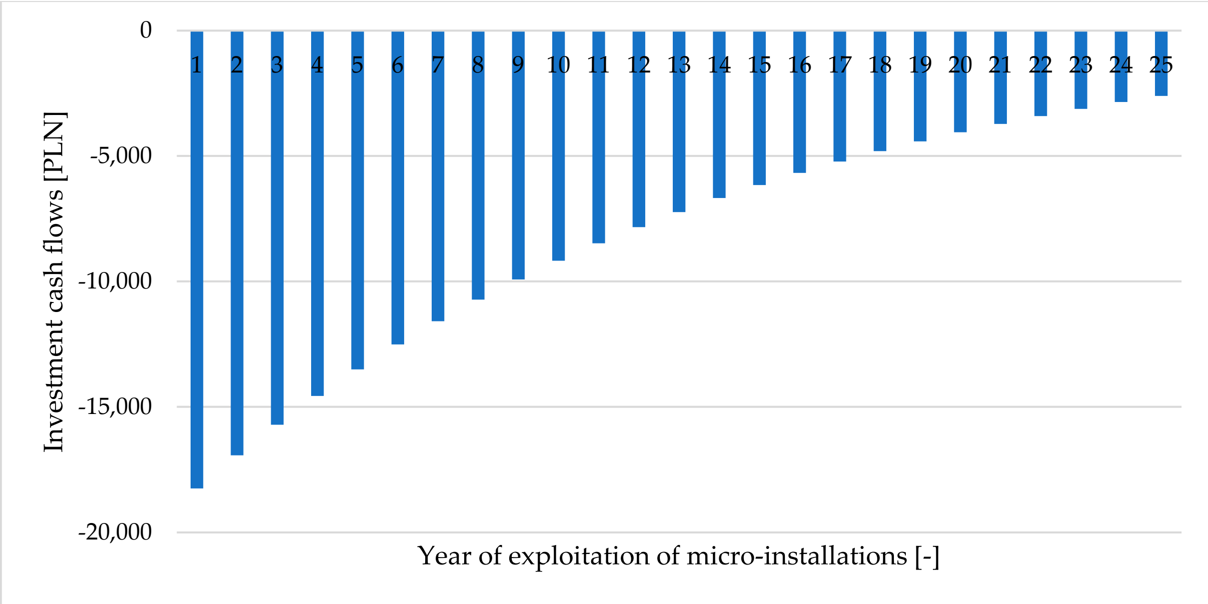


Figure 5. Graph showing the investment cash flow as a function of time of operation for the net-billing system based on monthly prices and a 30% self-consumption level.

When comparing Figures 4 (net-metering system) and 5 (net-billing system), it can be noted that in the case of the latter, the return on investment does not occur at all, throughout the lifetime of the micro-installation. In this case, it is necessary to analyse the assumptions made, such as the power of the PV installation or the level of current own electricity consumption. It should also be borne in mind that the sale and purchase prices of electricity have been taken into account at a given level with a certain annual increase (2%). However, this is a value that is very difficult to predict, especially over such a long period of time (25 years) and with recent geopolitical events affecting financial and economic markets.

3.5. Electricity Billing Based on Hourly Prices in the Net-Billing System

The third system that will be analysed in terms of economic viability for the designed PV installation is net-billing based on hourly prices. This is the target system, which is to be implemented in Poland as of 1 July 2024. Of all the variants, it is the most detailed, and thus, labour-intensive and complicated system in terms of the preparation of the economic analysis. The operating process for net-billing based on hourly prices is very similar to net-billing based on monthly electricity prices. However, in this case, the sale and purchase of energy is a much more dynamic phenomenon, as their values change with hourly frequency.

When preparing the economic analysis for this system, each year of the life of the investment under consideration was divided into quarters: I (January, February, March), II (April, May, June), III (July, August, September), and IV (October, November, December). For each of these, a profile was prepared for electricity production from the micro-installation using the diagram of average hourly profiles found on the Global Solar Atlas. This diagram is shown in Figure 6. From the diagram, it is possible to determine the average electricity production from the designed PV installation. For example, for the first quarter, the average number of hours in which energy is produced is 29, which is 16.36% of the total annual production.

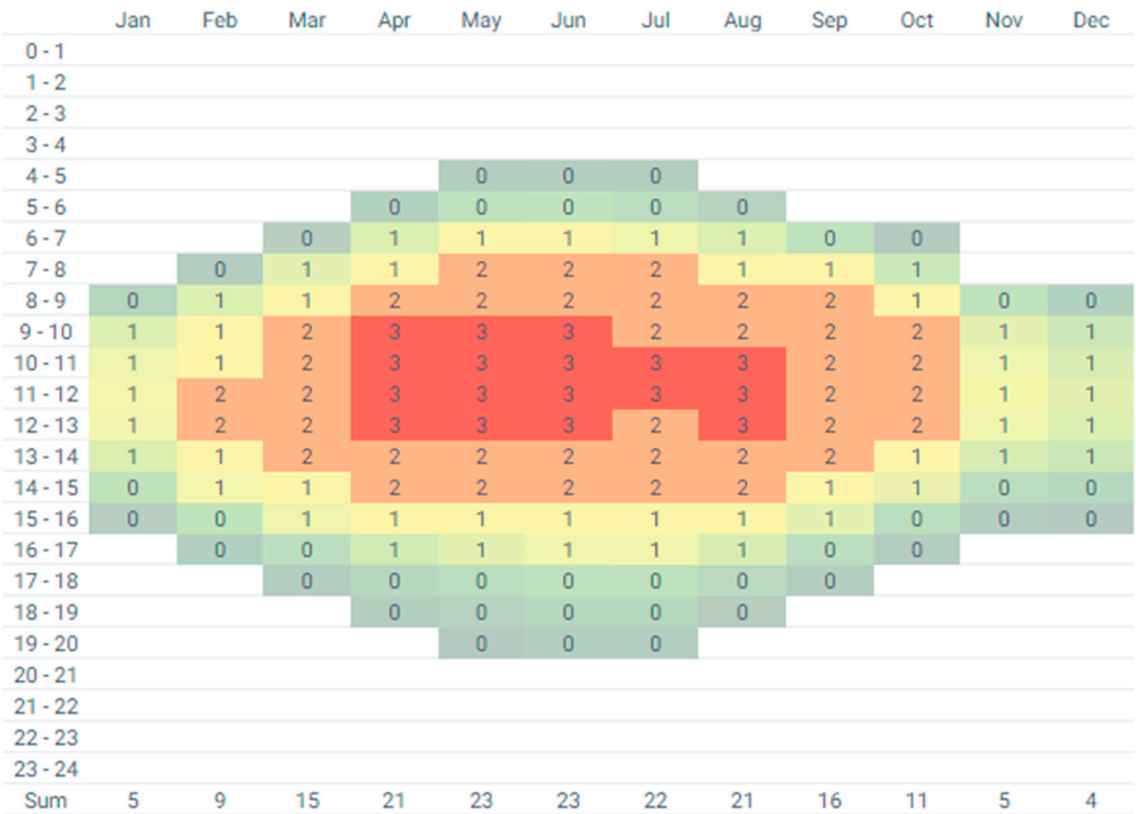


Figure 6. Diagram showing the average hourly electricity production profile for the designed photovoltaic system [50].

Using the above data, the percentage electricity production for the quarters in question was determined, and it looks as follows:

- Quarter 1: 16.36%;
- Quarter 2: 38.22%;
- Quarter 3: 34.06%;
- Quarter 4: 11.36%.

Based on the data presented in Figure 6, the hourly profile of production of electricity from the photovoltaic installation for each quarter was determined, as shown in Table 5.

Table 5. Hourly profile of production of energy from the micro-installation on a percentage basis.

Hour	Quarter I	Quarter II	Quarter III	Quarter IV
5:00	-	-	-	-
6:00	-	1.74%	1.62%	-
7:00	-	1.74%	1.62%	-
8:00	1.82%	3.47%	3.24%	1.42%
9:00	1.82%	5.21%	3.24%	1.42%
10:00	1.82%	5.21%	4.87%	2.84%
11:00	3.63%	5.21%	4.87%	2.84%
12:00	3.63%	5.22%	4.88%	1.42%
13:00	1.82%	3.47%	3.24%	1.42%
14:00	1.82%	3.47%	3.24%	-
15:00	-	1.74%	1.62%	-
16:00	-	1.74%	1.62%	-
17:00	-	-	-	-

Based on the data mentioned above and the knowledge of the annual production of electricity from the micro-installation, it was possible to prepare tables in a spreadsheet that showed the hourly production of electricity for each quarter over a period of 25 years. In the next step, a household energy demand profile was prepared and presented in Table 6 (spring–summer period) and Table 7 (autumn–winter period). These identified:

- The hourly electricity demand on a quarterly and annual basis;
- The hourly self-consumption of the electricity produced by the photovoltaic installation;
- The quantity of energy that will need to be purchased from the operator.

Table 6. An hourly profile of the household, which takes into account energy demand, self-consumption, and energy to be purchased on a quarterly and annual basis during the spring and summer periods.

Hour	Quarterly Energy Demand [kWh]	Annual Energy Demand [kWh]	Quarterly Self-Consumption [kWh]	Annual Self-Consumption [kWh]	Quarterly Energy Purchase [kWh]	Annual Energy Purchase [kWh]
1:00	-	-	-	-	-	-
2:00	-	-	-	-	-	-
3:00	-	-	-	-	-	-
4:00	-	-	-	-	-	-
5:00	-	-	-	-	-	-
6:00	-	-	-	-	-	-
7:00	112.5	450	67.5	270	45	180
8:00	112.5	450	67.5	270	45	180
9:00	112.5	450	67.5	270	45	180
10:00	112.5	450	67.5	270	45	180
11:00	112.5	450	67.5	270	45	180
12:00	-	-	-	-	-	-
13:00	-	-	-	-	-	-
14:00	-	-	-	-	-	-
15:00	-	-	-	-	-	-
16:00	-	-	-	-	-	-
17:00	-	-	-	-	-	-
18:00	112.5	450	-	-	112.5	450
19:00	112.5	450	-	-	112.5	450
20:00	112.5	450	-	-	112.5	450
21:00	112.5	450	-	-	112.5	450
22:00	112.5	450	-	-	112.5	450
23:00	-	-	-	-	-	-
00:00	-	-	-	-	-	-

Table 7. An hourly profile of the household, which takes into account energy demand, self-consumption, and energy to be purchased on a quarterly and annual basis during the autumn and winter periods.

Hour	Quarterly Energy Demand [kWh]	Annual Energy Demand [kWh]	Quarterly Self-Consumption [kWh]	Annual Self-Consumption [kWh]	Quarterly Energy Purchase [kWh]	Annual Energy Purchase [kWh]
1:00	-	-	-	-	-	-
2:00	-	-	-	-	-	-
3:00	-	-	-	-	-	-
4:00	-	-	-	-	-	-
5:00	-	-	-	-	-	-
6:00	-	-	-	-	-	-
7:00	-	-	-	-	-	-
8:00	112.5	450	67.5	270	45	180

9:00	112.5	450	67.5	270	45	180
10:00	112.5	450	67.5	270	45	180
11:00	112.5	450	67.5	270	45	180
12:00	112.5	450	67.5	270	45	180
13:00	-	-	-	-	-	-
14:00	-	-	-	-	-	-
15:00	-	-	-	-	-	-
16:00	-	-	-	-	-	-
17:00	-	-	-	-	-	-
18:00	112.5	450	-	-	112.5	450
19:00	112.5	450	-	-	112.5	450
20:00	112.5	450	-	-	112.5	450
21:00	112.5	450	-	-	112.5	450
22:00	112.5	450	-	-	112.5	450
23:00	-	-	-	-	-	-
00:00	-	-	-	-	-	-

The next step in determining the profitability of the investment is to determine the value of electricity prices on an hourly basis for each quarter. For this purpose, the data published on the website of *Polskie Sieci Elektroenergetyczne* (PSE) (Polish Transmission System Operator) under the Market Electricity Price (RCE) tab were used [46]. The determined averaged values of electricity prices at a given hour in a given quarter are presented in Table 8. It should be emphasised that these are electricity price values for the first year of operation of the micro-installation. An annual increase in these prices was assumed to be 2%.

Table 8. Hourly sales prices for the electricity produced from the photovoltaic installation in the first year of the system's operation. Data from PSE [54].

Hour	Quarter I	Quarter II	Quarter III	Quarter IV
	[PLN/MWh]	[PLN/MWh]	[PLN/MWh]	[PLN/MWh]
1:00	546.38	683.83	842.80	446.04
2:00	511.98	617.66	755.99	422.00
3:00	500.97	600.39	743.52	396.80
4:00	496.70	600.10	752.52	394.75
5:00	513.09	613.91	753.24	411.73
6:00	536.11	637.96	746.96	450.88
7:00	643.30	702.41	907.23	569.74
8:00	620.05	714.34	824.08	573.12
9:00	685.26	741.48	872.76	690.52
10:00	699.20	687.44	739.17	695.57
11:00	660.95	618.10	668.33	635.02
12:00	671.87	577.61	653.84	631.72
13:00	655.52	550.02	655.05	616.69
14:00	673.49	512.17	628.49	627.00
15:00	679.97	501.40	616.36	607.79
16:00	727.51	523.94	643.94	621.72
17:00	855.21	558.58	669.26	682.84
18:00	985.29	643.85	750.07	711.27
19:00	1007.80	732.84	945.98	654.25
20:00	988.02	854.52	1224.74	636.84
21:00	872.85	938.82	1277.74	556.11
22:00	672.90	872.96	1201.73	448.71
23:00	657.43	837.20	1137.76	499.24
00:00	546.55	718.70	885.08	438.29

Once the household energy profile was plotted against the micro-installation electricity production profile, the quantity of energy to be sold to the grid over a given period was determined. Data indicating the net present value and the profitability of the investment for energy billing based on hourly prices are included in Table A3. Figure 7 shows the variation of cash flows of a photovoltaic installation as a function of its operating time. Unfortunately, as in the previous case (net-billing based on monthly prices), there will not be a point here where the investment becomes profitable with the assumptions made over the specified lifetime of the system.

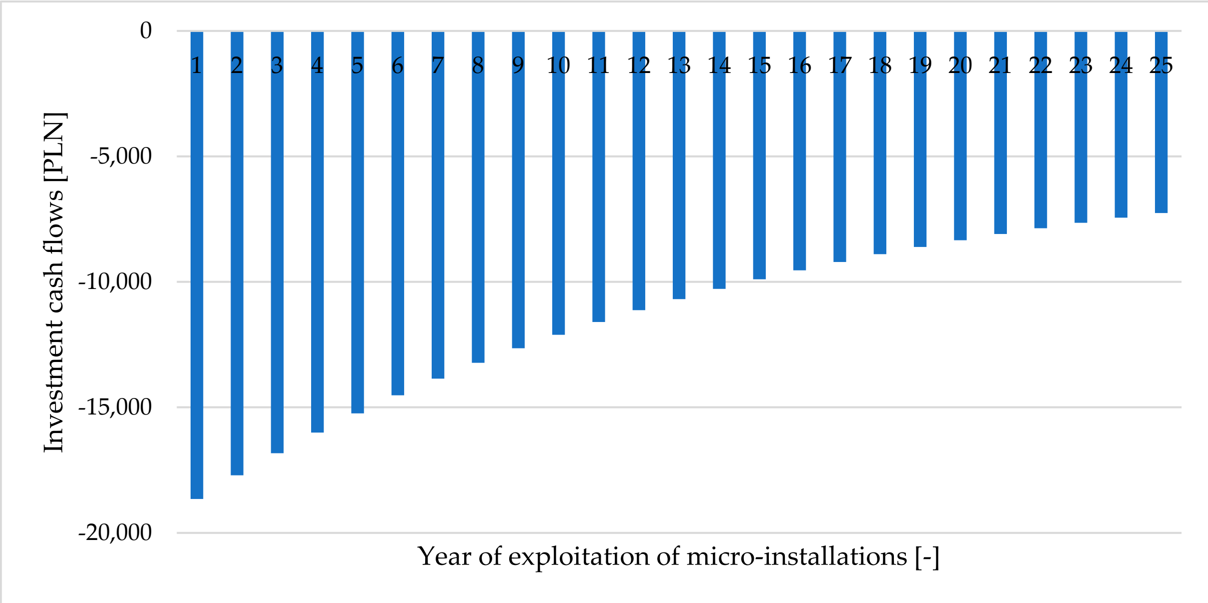


Figure 7. Graph showing the cash flow of the investment as a function of time of its operation for the net-billing system based on hourly prices and a 30% self-consumption level.

When comparing Figure 5 (net-billing based on monthly prices) and Figure 7 (net-billing based on hourly prices), it can be observed that, in the case of the latter, the investment cash flows change at a much slower speed. At this point, it should be stressed again that the graphs could have had a completely different shape if different assumptions had been chosen. For the assumptions made, the cash flows in this case after 25 years of operation amounted to as much as −PLN 12,300 (compared to −PLN 2600 for billing at monthly prices). Assuming given purchase and sales prices for electricity these days is a very uncertain exercise. Above all, it should be borne in mind that net-billing systems are intended to encourage investors to procure devices that increase the proportion of self-consumption, such as electricity storages. It is a system aimed at increasing prosumers' energy awareness and motivating them to self-manage the electricity they produce.

3.6. NPV Analyses of PV Installations for Different Energy Billing Scenarios with a 50% Self-Consumption Level

The NPV analysis carried out above for the assumptions made did not bring satisfactory results in terms of economic indicators. This is mainly due to the method of billing the energy produced in a prosumer PV installation and the low level of utilisation of the current energy production. In order to improve the NPV and shorten the payback time of the investment, consideration should be given, first and foremost, to increasing the level of self-consumption of energy by, for example, installing smart energy meters along with automation systems to manage the energy flow in the home installation, allowing appliances to be activated at times of high energy production. Another possible measure is the installation of energy storage for the later use of the energy or its sale to the grid during the evening/night hours when higher prices can be obtained. A schematic representation of a standard load profile for a single-family house with production of energy by a PV installation and the possibility to change the level of self-consumption from 30% to 50% is shown in Figure 8 (the switching on of the electric heater in the boiler has been changed from 8 p.m. to 1 p.m.). In turn, a diagram of the installation expanded with the aforementioned elements is shown in Figure A2 in Appendix A.

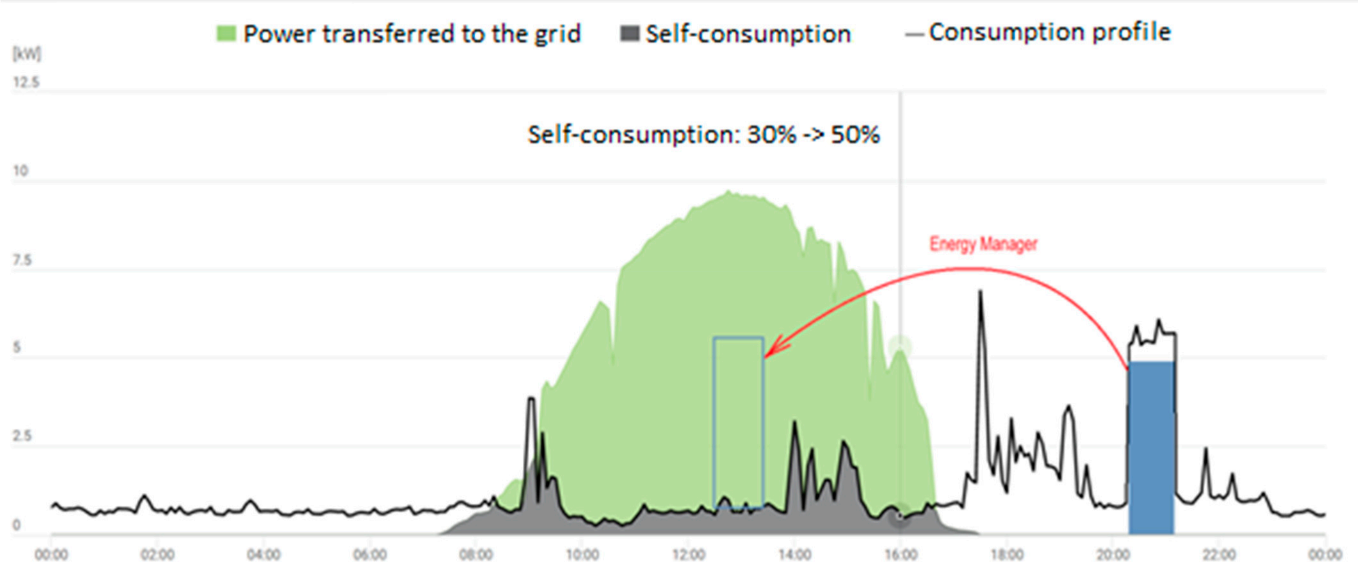


Figure 8. Load and electricity production profile for a single-family house [55].

In view of the above, a recalculation was made in which the self-consumption of the produced electricity from the household photovoltaic installation is higher and amounted to 50%. The other assumptions of the analysis did not change. However, in the last variant, i.e., the net-billing system based on hourly prices, it was necessary to interfere with the hourly profile of the household, which takes into account the level of self-consumption in a given hour. For this reason, it was assumed that the use of the energy produced from the micro-installation by the household in the following quarters was constant and the same in each hour in which energy from the PV system was produced. This amounted to approximately 64.3 kWh and was as follows:

- Quarter I, electricity production from the PV installation from 8:00 a.m. to 2:00 p.m.;
- Quarter II, electricity production from the PV installation from 6:00 a.m. to 4:00 p.m.;
- Quarter III, electricity production from the PV installation from 6:00 a.m. to 4:00 p.m.;
- Quarter IV, electricity production from the PV installation from 08:00 a.m. to 1:00 p.m.

This means that the predicted annual use of household electricity will be about 2250 kWh with an energy demand of 4500 kWh/year.

The obtained results of the calculations are presented in Tables A4–A6 and Figures 9–11, showing the profitability of the investment for the analysed three scenarios of billing the electricity produced from the micro-installation.

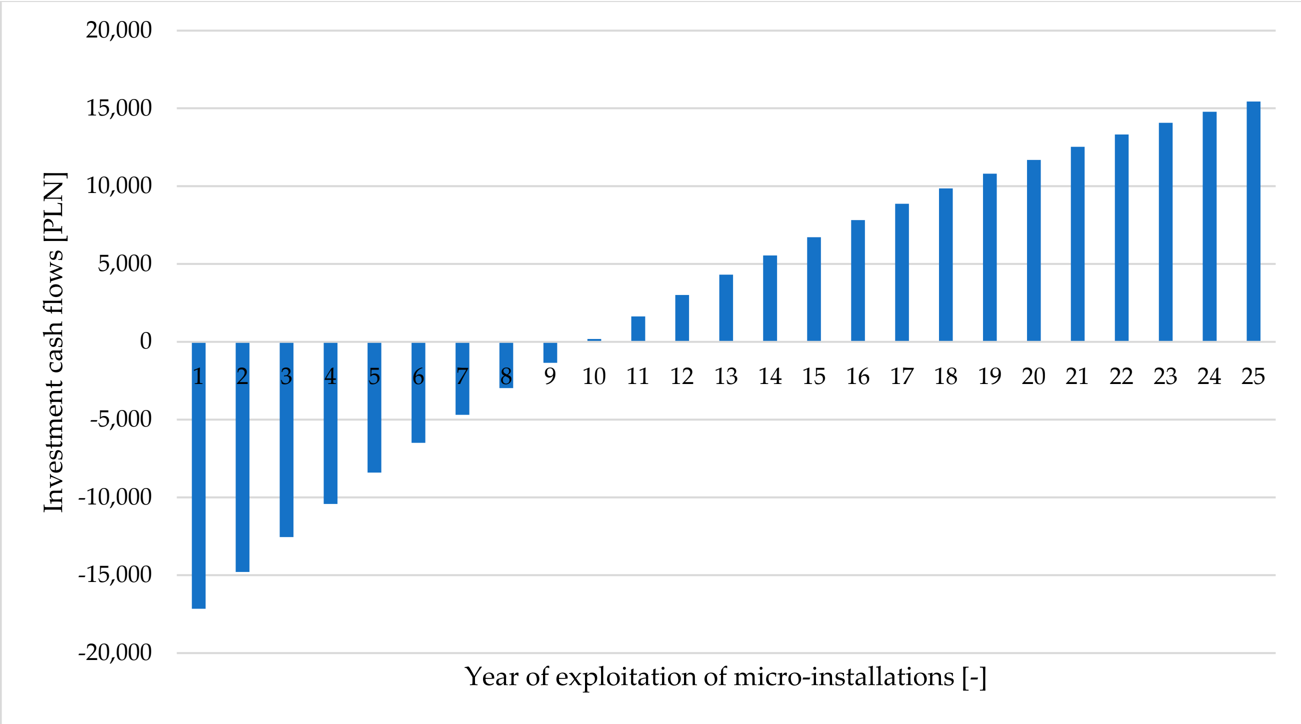


Figure 9. Graph showing the payback period for the capital expenditures incurred in relation to the net-metering system and the 50% self-consumption level.

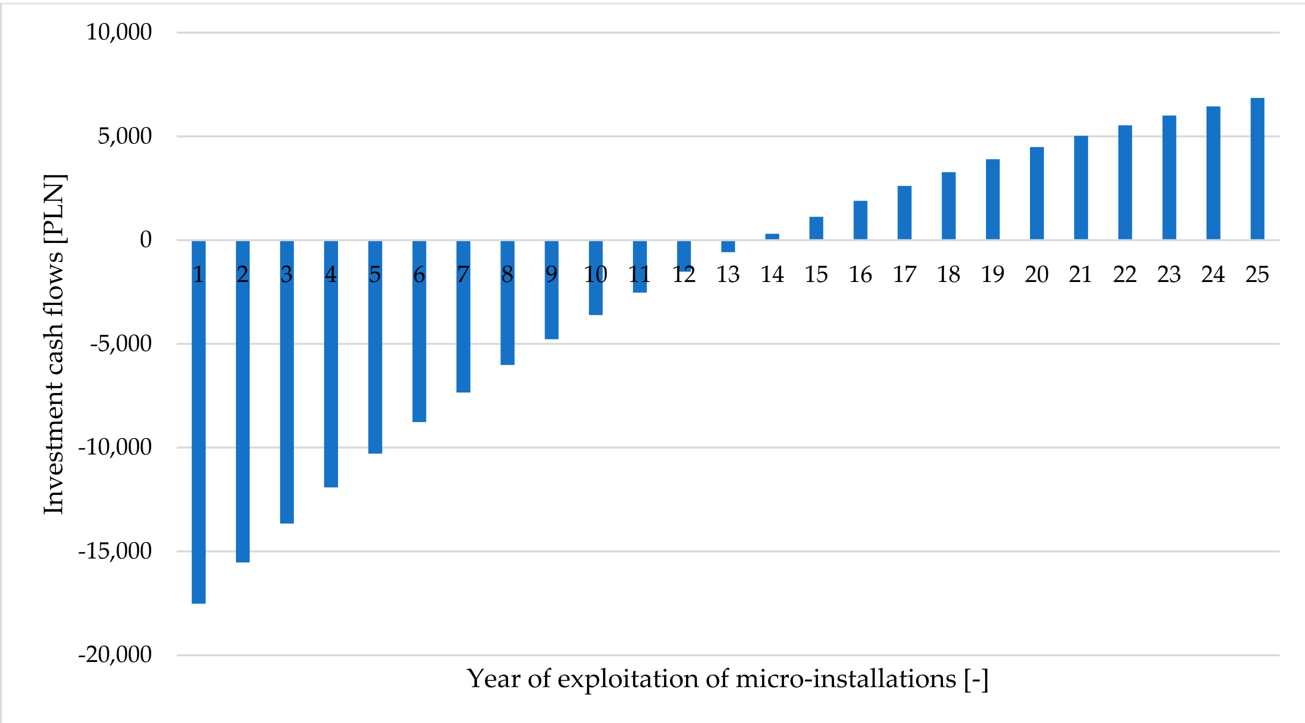


Figure 10. Graph showing the investment cash flow as a function of time of operation for the net-billing system based on monthly prices and a 50% self-consumption level.

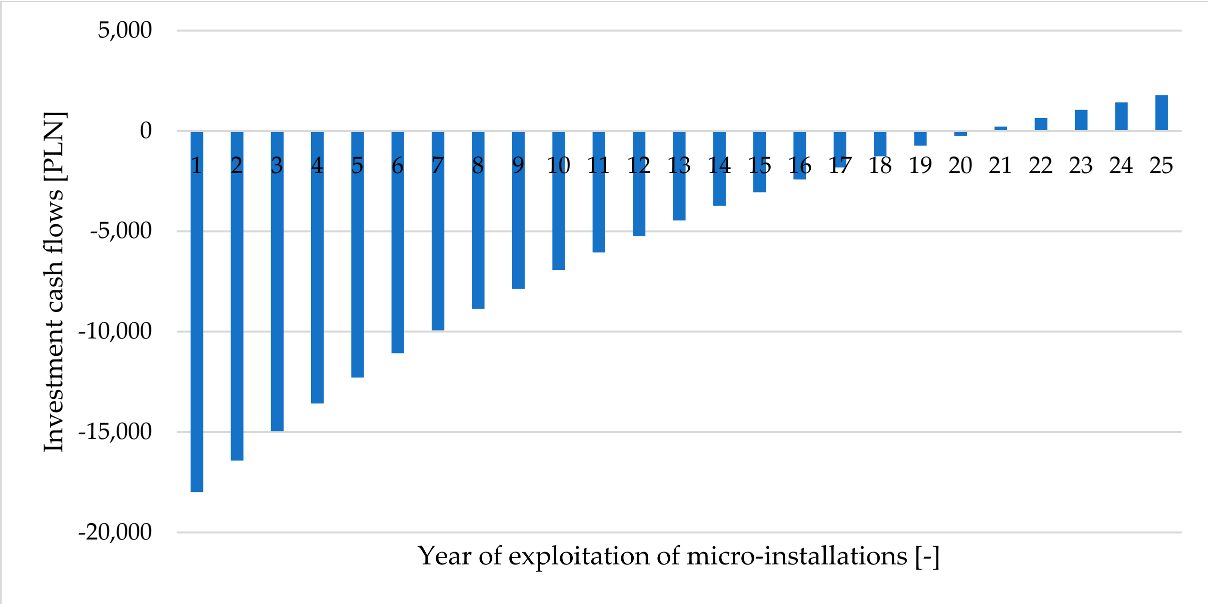


Figure 11. Graph showing the cash flow of the investment as a function of time of its operation for the net-billing system based on hourly prices and a 50% self-consumption level.

Observing the results of the economic analysis above, in the case of a net-billing system, increasing the level of self-consumption definitely shortens the investment payback period. In the variant under consideration based on monthly prices, the designed installation has proven to be profitable, as the investment cash flows are positive in the 14th year of operation of the photovoltaic system. In contrast, in the net-billing-system based on hourly prices, despite a significant increase in self-consumption, the moment of payback of the costs incurred will not take place throughout the lifetime of the photovoltaic system. Despite this fact, by comparing the graphs when its value was 30% (Figure 7) and when it was increased to 50% (Figure 11), it can be observed that in the last year of the period under consideration, the investment cash flows declined significantly.

The anticipated effect of increasing the level of use of the electricity produced from the photovoltaic installation from 30% to 50% was a shortening of the payback period of the capital expenditure. Just as it turned out to be true in the considered variants of the net-billing-system, in the case of discounts, an increase in self-consumption did not significantly affect the profitability of the investment. In both cases, net-metering brings the first real financial benefits in the 10th year of the system's operation. This means that, for this case, a change in the level of self-consumption does not bring major benefits.

Another analysis was carried out for a PV installation with a self-consumption level of 50%, but additionally equipped with a FRONIU SOLAR BATTERY 4.5 energy storage with a capacity of 4.5 kWh. According to the energy storage manufacturer's data sheet [56], its guaranteed capacity is 3.6 kWh. In addition to the inverter and the energy storage, the photovoltaic system was additionally provided with a smart bi-directional meter that allows for the monitoring of the energy used for own consumption and that sent to the power grid—the Fronius Smart Meter, as shown in Figure A2 (in Appendix A). The cost of the energy storage and smart meter was estimated at PLN 15,000.

The exact results of the NPV indicators for the mechanism of energy billing at hourly prices with the energy storage used are presented in Table A7 and Figure 12.

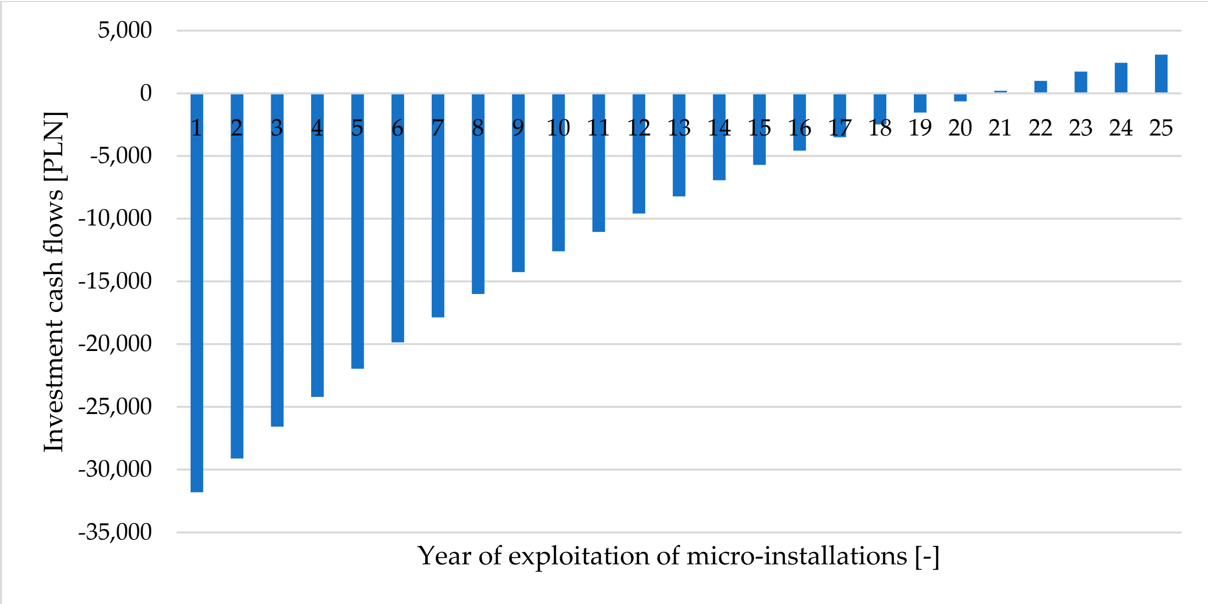


Figure 12. Graph showing the cash flow of the investment as a function of time of its operation for the net-billing system based on hourly prices and 50% self-consumption level with energy storage.

The operation of the energy storage was designed as follows: the battery stores 3.6 kWh of electricity produced from the PV installation each day (during the midday hours with high production and low consumption and low energy sales prices). This energy is then sent to the power grid in the evening to be sold at a higher price. Over the 25 years of operation of the PV system, this action has allowed for the saving of just over PLN 3000, despite much higher initial capital expenditure.

3.7. NPV Analyses of PV Installations for Different Energy Billing Scenarios with 60% Self-Consumption Level

The last analysed variant of energy use for the prosumer’s current needs was 60%. After the relevant calculations, positive NPV values were already obtained for each of the billing mechanisms, as is presented in Tables A8–A10 and Figures 13–15.

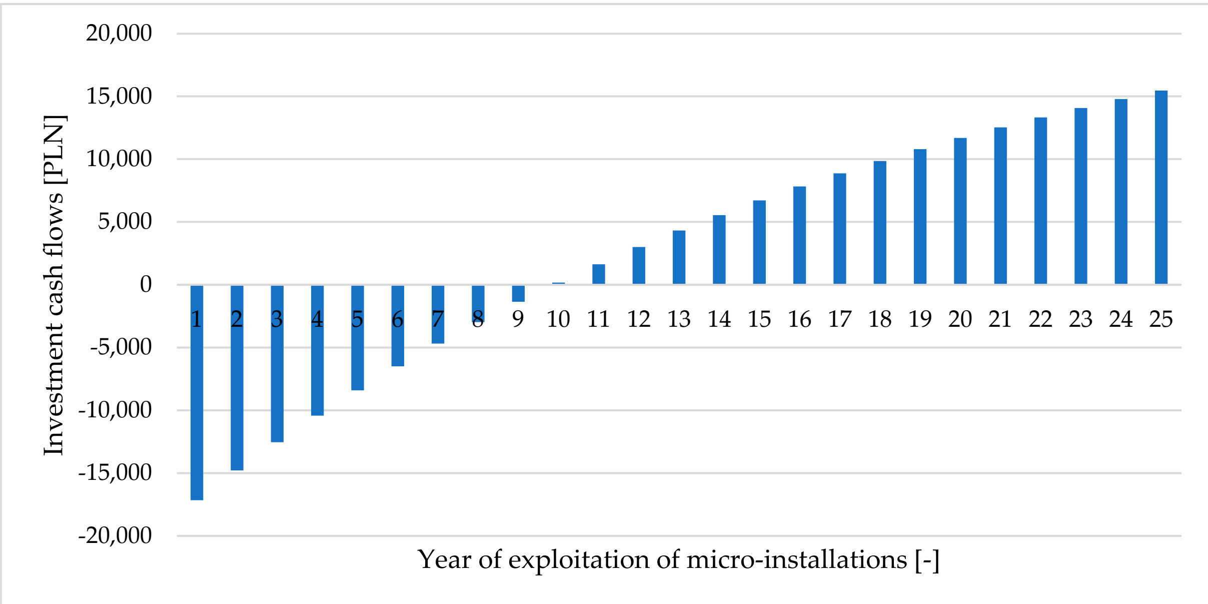


Figure 13. Graph showing the payback period for the capital expenditures incurred in relation to the net-metering system and the 60% self-consumption level.

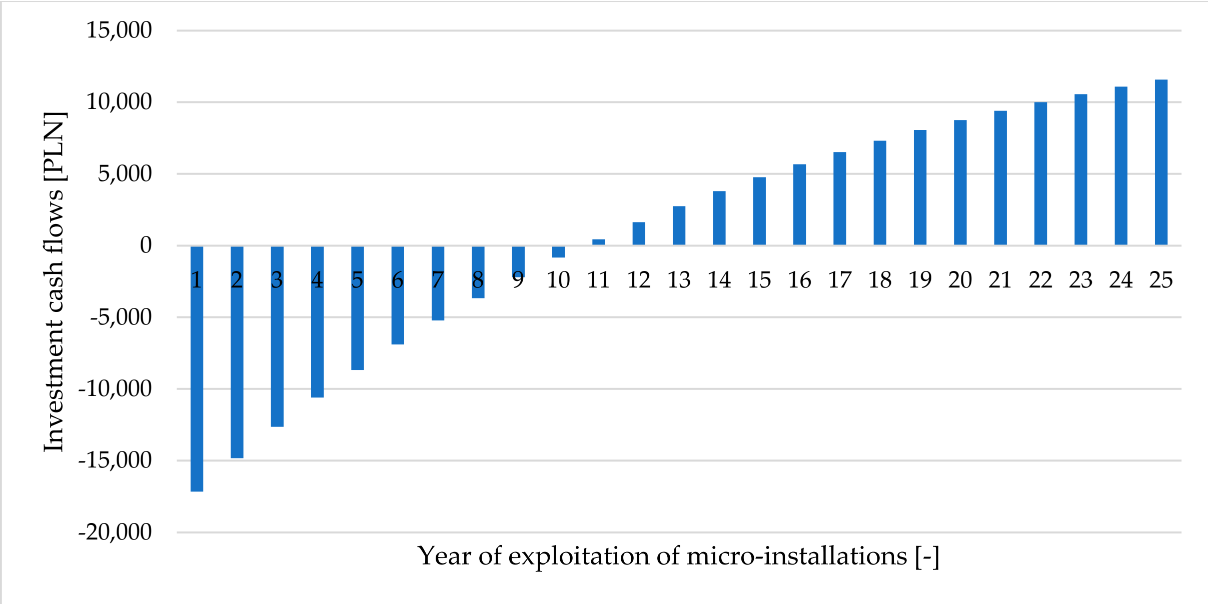


Figure 14. Graph showing the investment cash flow as a function of time of operation for the net-billing system based on monthly prices and a 60% self-consumption level.

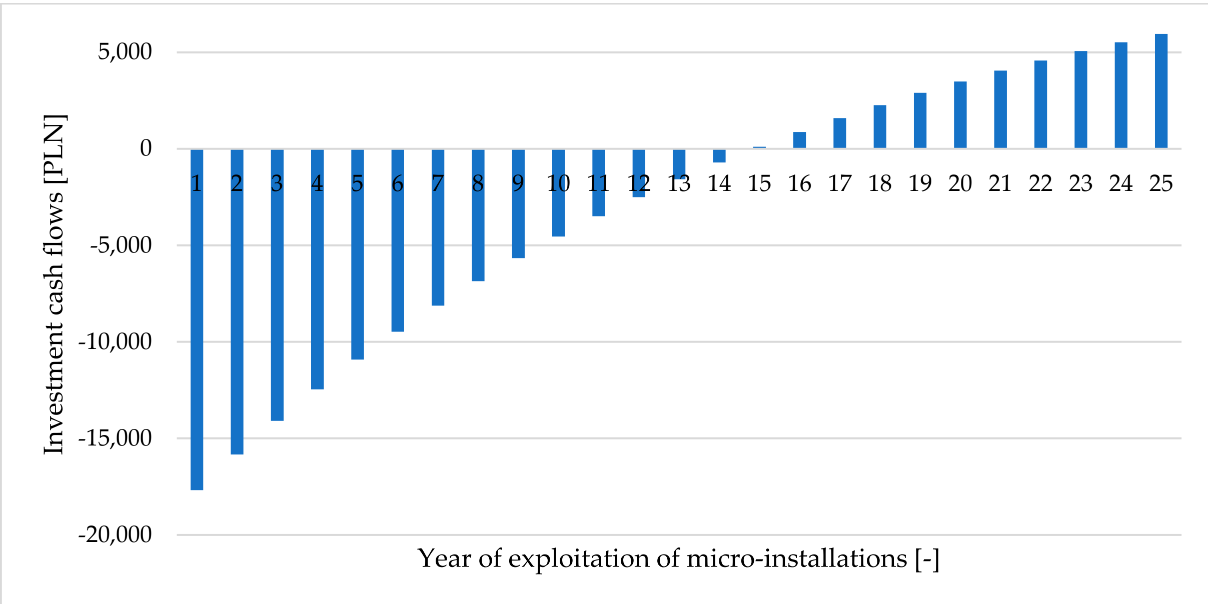


Figure 15. Graph showing the cash flow of the investment as a function of time of its operation for the net-billing system based on hourly prices and a 60% self-consumption level.

When analysing the increased level of electricity self-consumption from 50% to 60%, an increase in NPV values for the energy billing systems at monthly and hourly prices is observed. For the discount system, the NPV changes only slightly, as in the previously analysed case. A 10% increase in the level of current energy consumption resulted in a reduction in payback time of three years for energy billing at monthly prices and as much as six years for hourly prices. With 60% self-consumption of electricity, the investment payback period when billing electricity at hourly prices and according to the principle of discounts practically became almost equal and amounted to approximately 10–11 years, but the final value of the NPV is approximately 2.5 times lower.

4. Discussion

The presented change in the billing model for electricity produced by prosumer PV micro-installations clearly shows a deterioration in the profitability of investments in low-power PV systems at current energy price rates. The existing electricity billing system based on net-metering has contributed to new investments in home PV installations by individual investors owing to the short payback time of the invested funds of a few years (max. 10). In the discount system, the level of current self-consumption did not have a big impact on the final financial indicators, e.g., NPV after 25 years of the PV installation's life. The only increases in NPV with an increase in the level of self-consumption were due to the savings of not giving the DSO 20% of the energy sent to the grid for later collection. The new electricity billing model for PV installations changes the concept of using the grid as an energy storage, forcing prosumers to increase the level of self-consumption or install local energy storages in order to relieve the load on the low-voltage power grid and reduce the problems for operators resulting from the addition of new unstable energy sources, whose production does not coincide with periods of energy demand. Table 9 lists the NPVs obtained for the analysed electricity billing systems, depending on the assumed level of electricity self-consumption or the use of an energy storage. Pictorially, these results are presented in the graph (Figure 16).

Table 9. Summary of NPVs for the PV installations analysed.

Self-Consumption [%]	The Principle of Accounting for Energy	NPV after 25 Years of Operation [PLN]	Payback Time [year]
30	Rebate	15,135.20	10
	Monthly price	−2605.03	>25
	Hourly price	−7258.59	>25
50	Rebate	15,437.19	10
	Monthly price	6849.34	14
	Hourly price	1777.41	21
	Hourly price + energy storage	3075.63	21
60	Rebate	15,459.56	10
	Monthly price	11,576.53	11
	Hourly price	5953.77	15

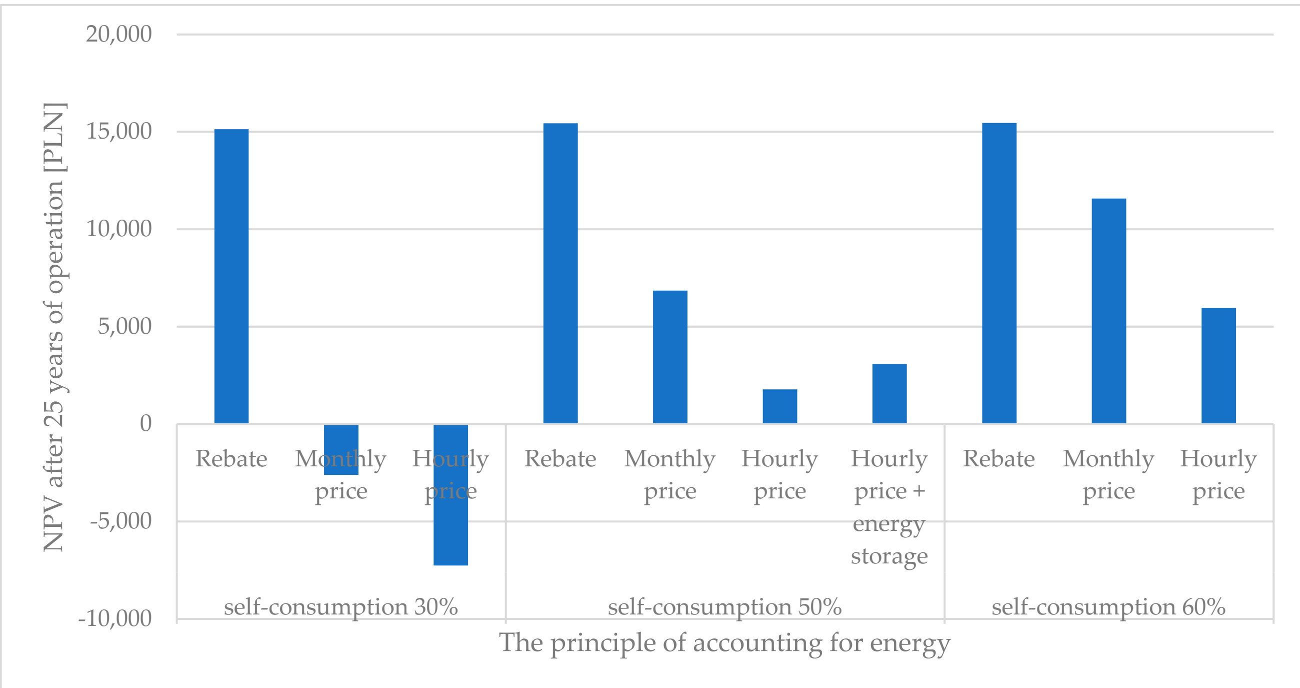


Figure 16. Graph of changes in NPVs for the PV installations analysed.

It can be seen that the NPV changes significantly for net-billing systems. The greater the dynamics of change is, the higher the frequency is of energy price changes. For the analysed period, the year 2022, according to the data provided by the *Polskie Sieci Energetyczne* (Polish Transmission System Operator) and *Towarowa Giełda Energii* (Polish Power Exchange), which publish energy prices on a monthly (RCM Monthly Price Market) and hourly basis, the NPVs change dynamically, indicating that investments in PV systems are justified, if certain assumptions are fulfilled. Only when approximately 50% of the energy is used for current household needs are positive NPV ratios visible for each of the billing systems analysed. The payback time also decreases with increased levels of self-consumption. For the current, most common level of self-consumption of 30%, it is possible to achieve a payback time of approximately 10 years in the discount system alone, with an assumed lifetime of 25 years for the installation. For systems based on net-billing, there would be no payback over the entire life of the installation. Only the consumption of at least half of the energy produced on current basis would allow for the return of the capital expenditures incurred. A very high dynamic of payback time can be observed when the level of self-consumption is increased from 50% to 60%. Just a 10% change would allow the payback time to be reduced by three years (from 14 to 11 years) for billing at monthly prices, and by as much as six years (from 21 to 15 years) for billing at hourly prices. Additionally, the use of an energy storage allows for the achievement of a payback time that is shorter than the lifetime of the installation (approximately 21 years), for a level of self-consumption of 50%, both for installations with and without an energy storage. However, the NPV of the installation with the energy storage almost doubled (compared to the installation without it), despite an almost 75% higher capital expenditure, which indicates that its installation is justified.

5. Summary

Renewable energy, in particular photovoltaic installations, offers many advantages. It is a form of electricity generation particularly dedicated to low-power installations of individual consumers, known as prosumers. The relatively low investment costs and ease of construction of PV systems have resulted in the widespread use of these types of generation systems in many countries. The payback time is another element determining the spread of these types of systems. Not only is it related to investment costs, but above all, to the principles of settlement of the energy produced with the power operator, established by each individual country in the legislative process. The change from net-metering to net-billing of electricity produced in RES installations in Poland has necessitated a review of the profitability of such investments. Despite the fact that similar billing systems are used in other European countries, it is only the combination of accurate billing rules, climatic conditions, and the energy consumption profile of households that make reliable and credible economic analyses of planned projects possible.

The mechanisms for the selection of installation capacity for a prosumer photovoltaic installation, energy billing methods, and the change of the load profile presented in the publication can provide information on the rationale for investment. The mechanisms for establishing the load profile of the household and analyses of energy consumption for one’s own purposes, and the creation of guidelines for billing at hourly prices, presented with Poland as an example, can be successfully applied in other countries where billing is based on net-billing principles, after taking into account the specific conditions of the given country. The analysis of a specific installation tilted by 20° to the east introduces approximately 1% reduction in the value of generated power compared to the installation oriented to the south. Additionally, the obtained results of the analysis can be considered general, for installations with a deviation of ±20° from the south. In addition, slightly better indicators can be obtained when the installation is directed to the west, when in summer periods hourly energy sales prices in the evening are slightly higher than in the morning, but again, these differences in annual terms will be marginal and will not affect the general trend of changes in NPV indicators.

An increase in the level of electricity self-consumption will always have a positive impact on the final economic indicators and the payback time of the investment, especially in times of energy crisis and rising energy prices. The use of mechanisms designed to increase the level of self-consumption of electricity from own RES installations is also important, apart from economic indicators of course, from the point of view of the operation of the RES installations themselves and the operation of the power grid. Consuming electricity for one's own current needs contributes to relieving the load on the grid, reducing grid losses, and improving the most important grid parameters (such as voltage levels, voltage dips, and losses). On the other hand, the use of an energy storage in one's own installation also has a positive impact on economic indicators (as shown in the analyses presented, despite higher capital expenditure) and leads to greater stability and guarantees of power supply in emergency situations in the grid.

To sum up, it is necessary to further develop RES technologies and seek ways to increase the level of self-consumption (e.g., through the assembly of smart energy meters or energy flow management systems in the installation), which will contribute to environmental protection, fulfilment of climate policy objectives, and increase in financial gains for investors, including those at the micro-installation scale.

Author Contributions: Conceptualisation and methodology, D.K. and A.N.; validation, D.K.; formal analysis, A.N.; writing—original draft preparation, D.K. and A.N.; writing—review and editing, D.K. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

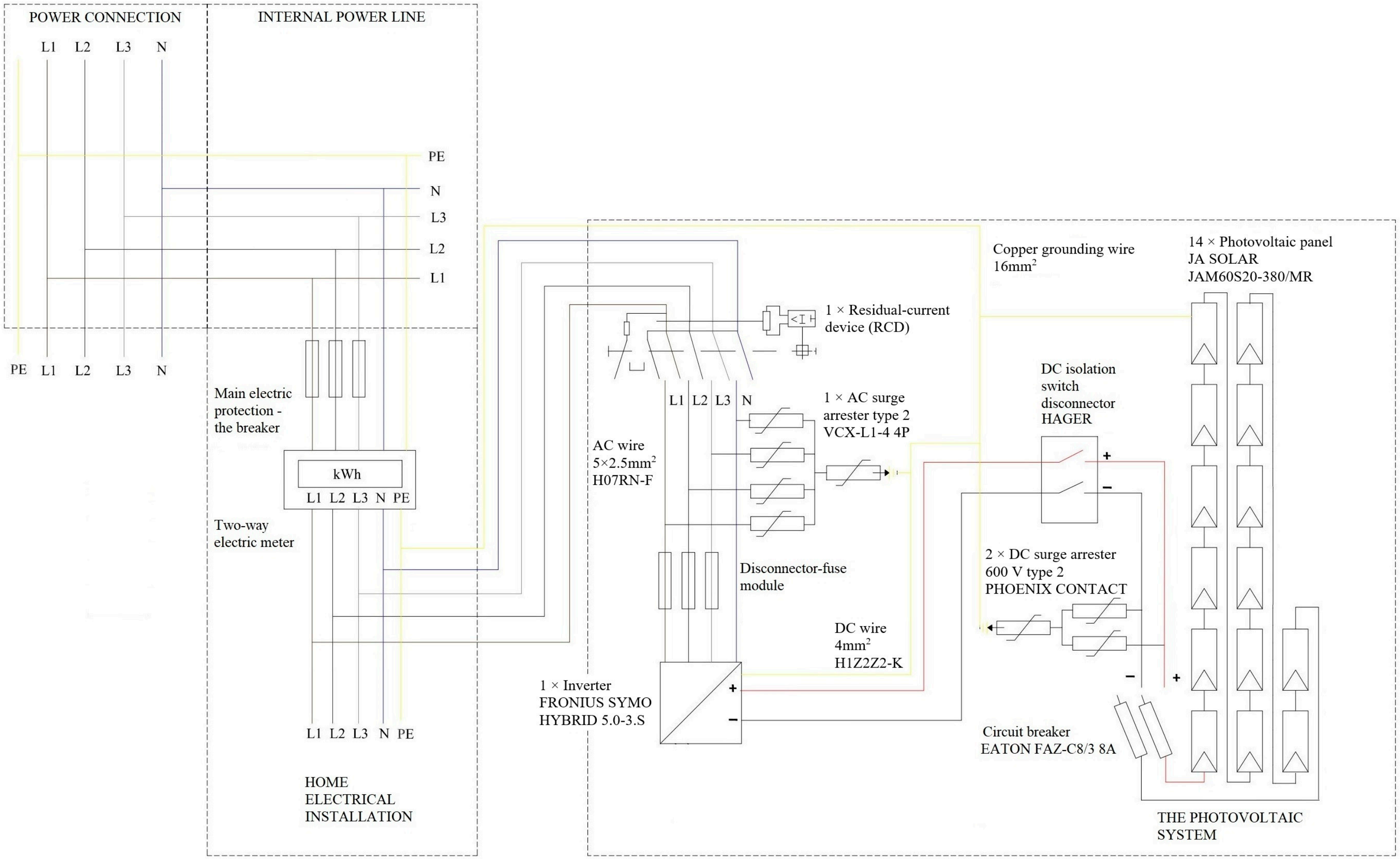

Figure A1. Electrical diagram of the designed photovoltaic installation.

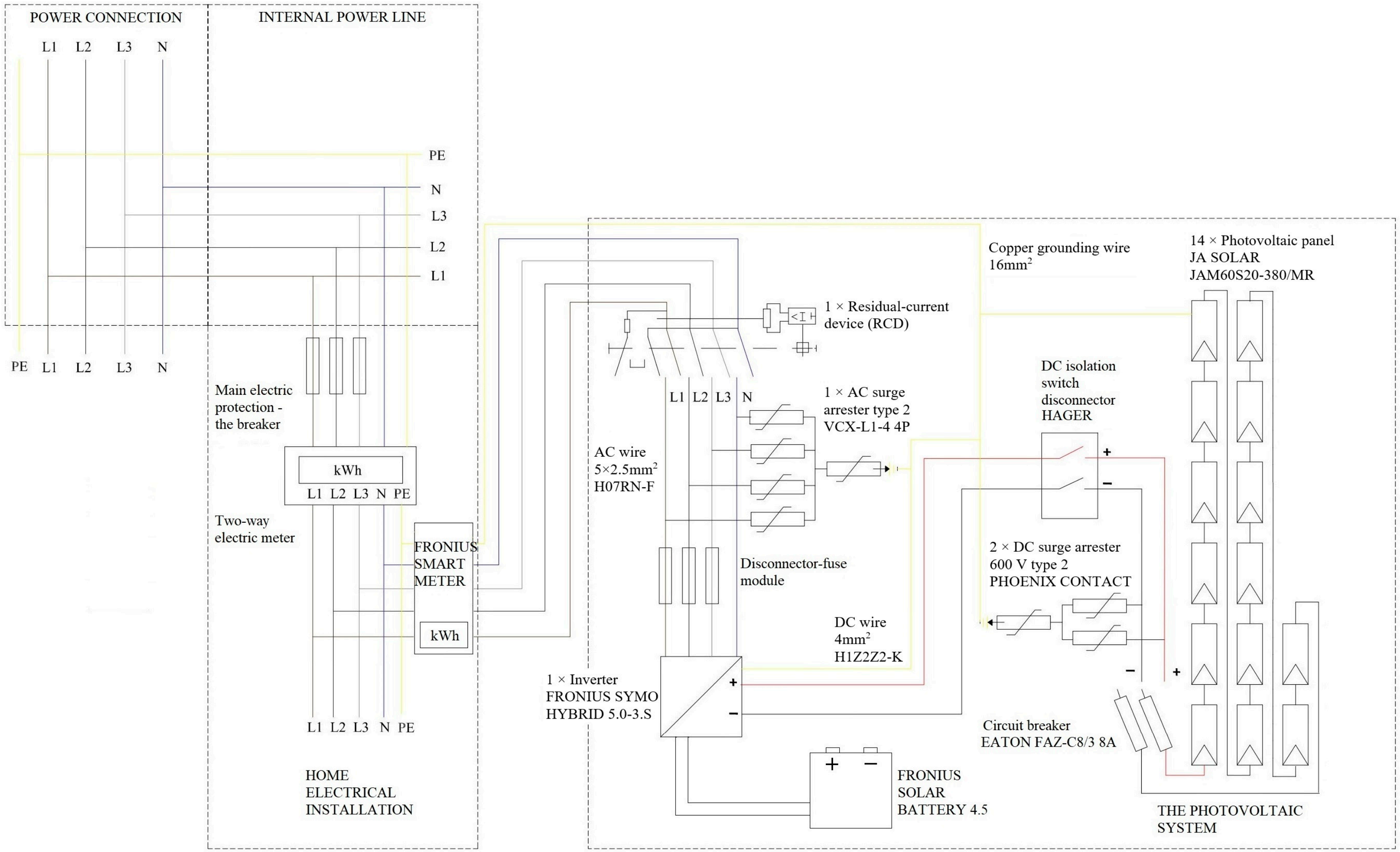

Figure A2. Electrical diagram of the designed photovoltaic installation extended by an energy storage and energy management system.

Table A1. NPV results of the PV installation for the discount system, at a 30% self-consumption level.

System Lifetime [Year]	Electricity Demand [kWh/Year]	Electricity Price [PLN/kWh]	Electricity Costs without a PV System [PLN/Year]	Electricity Needed from Grid (after Self-Consumption) [kWh/rok]	Electricity to be Picked up from the Grid [kWh/rok]	Difference of Electricity [kWh/rok]	Electricity Cost for Purchase from the Grid [PLN/Year]	Investment Outlays [PLN]	Operating Costs [PLN]	Discount rate [–]	Investor Cash Flow [PLN/year]	NPV [PLN]	Investment Profitability [PLN]
0	-	-	-	-	-	-	-	19,660	-	-	-	−19,660.00	−19,660.00
1	4500	0.70	3150.00	2813.70	3147.76	334.06	0	0	450	0.08	3150.00	2500.00	−17,160.00
2	4500	0.71	3213.00	2822.97	3130.45	307.48	0	0	450	0.08	3213.00	2368.83	−14,791.17
3	4500	0.73	3277.26	2832.20	3113.23	281.03	0	0	450	0.08	3277.26	2244.37	−12,546.80
4	4500	0.74	3342.81	2841.37	3096.10	254.73	0	0	450	0.08	3342.81	2126.30	−10,420.50
5	4500	0.76	3409.66	2850.49	3079.08	228.59	0	0	450	0.08	3409.66	2014.30	−8406.21
6	4500	0.77	3477.85	2859.57	3062.14	202.57	0	0	450	0.08	3477.85	1908.06	−6498.15
7	4500	0.79	3547.41	2868.59	3045.30	176.71	0	0	450	0.08	3547.41	1807.31	−4690.84
8	4500	0.80	3618.36	2877.56	3028.55	150.99	0	0	450	0.08	3618.36	1711.77	−2979.07
9	4500	0.82	3690.73	2886.48	3011.90	125.42	0	0	450	0.08	3690.73	1621.17	−1357.90
10	4500	0.84	3764.54	2895.36	2995.33	99.97	0	0	450	0.08	3764.54	1535.27	177.37
11	4500	0.85	3839.83	2904.18	2978.86	74.68	0	0	450	0.08	3839.83	1453.84	1631.21
12	4500	0.87	3916.63	2912.96	2962.47	49.51	0	0	450	0.08	3916.63	1376.65	3007.86
13	4500	0.89	3994.96	2921.69	2946.18	24.49	0	0	450	0.08	3994.96	1303.48	4311.34
14	4500	0.91	4074.86	2930.37	2929.98	−0.39	0.35	0	450	0.08	4074.51	1234.00	5545.34
15	4500	0.92	4156.36	2939.00	2913.86	−25.14	23.22	0	450	0.08	4133.14	1161.08	6706.42
16	4500	0.94	4239.49	2947.59	2897.83	−49.76	46.88	0	450	0.08	4192.61	1092.43	7798.85
17	4500	0.96	4324.27	2956.13	2881.90	−74.23	71.33	0	450	0.08	4252.94	1027.82	8826.67
18	4500	0.98	4410.76	2964.62	2866.05	−98.57	96.62	0	450	0.08	4314.15	967.00	9793.67
19	4500	1.00	4498.98	2973.06	2850.28	−122.78	122.75	0	450	0.08	4376.22	909.75	10,703.42
20	4500	1.02	4588.96	2981.46	2834.61	−146.85	149.75	0	450	0.08	4439.20	855.88	11,559.30
21	4500	1.04	4680.73	2989.81	2819.02	−170.79	177.65	0	450	0.08	4503.08	805.17	12,364.46
22	4500	1.06	4774.35	2998.12	2803.51	−194.61	206.47	0	450	0.08	4567.87	757.44	13,121.91
23	4500	1.08	4869.84	3006.38	2788.09	−218.29	236.23	0	450	0.08	4633.61	712.53	13,834.44
24	4500	1.10	4967.23	3014.59	2772.76	−241.83	266.94	0	450	0.08	4700.29	670.27	14,504.71
25	4500	1.13	5066.58	3022.76	2757.50	−265.26	298.66	0	450	0.08	4767.92	630.49	15,135.20

Table A2. NPV results of the PV installation for the net-billing system based on monthly prices, at a 30% self-consumption level.

System Lifetime [Year]	Electricity that was Purchased Self-Consumption Adjusted [kWh/Year]	Electricity Purchase Costs from the Grid [PLN/Year]	Electricity that has been Sold [kWh/Year]	Costs of Selling Electricity to the Grid [PLN/Year]	Savings Related to the Production of Electricity for Own Use [PLN/Year]	Investment Outlays [PLN]	Operating Costs [PLN]	Discount rate [-]	Investor Cash Flow [PLN/year]	NPV [PLN]	Investment Profitability [PLN]
0	-	-	-	-	-	19,660	-	-	-	−19,660.00	−19,660
1	2813.70	1969.59	3934.70	2761.20	1180.41	0	450	0.08	1972.02	1409.28	−18,250.7
2	2822.97	2004.31	3913.06	2800.93	1190.69	0	450	0.08	1987.31	1318.00	−16,932.7
3	2832.20	2067.50	3891.54	2841.24	1217.50	0	450	0.08	1991.23	1223.48	−15,709.2
4	2841.37	2102.62	3870.13	2882.12	1227.38	0	450	0.08	2006.89	1144.36	−14,564.9
5	2850.49	2166.38	3848.85	2923.60	1253.62	0	450	0.08	2010.84	1062.28	−13,502.6
6	2859.57	2201.87	3827.68	2965.67	1263.13	0	450	0.08	2026.93	993.73	−12,508.9
7	2868.59	2266.18	3806.63	3008.35	1288.82	0	450	0.08	2030.98	922.49	−11,586.4
8	2877.56	2302.05	3785.69	3051.64	1297.95	0	450	0.08	2047.54	863.10	−10,723.3
9	2886.48	2366.92	3764.87	3095.55	1323.08	0	450	0.08	2051.71	801.25	−9922.03
10	2895.36	2432.10	3744.16	3140.09	1347.90	0	450	0.08	2055.89	743.84	−9178.19
11	2904.18	2468.56	3723.57	3185.28	1356.44	0	450	0.08	2073.17	696.15	−8482.04
12	2912.96	2534.28	3703.09	3231.12	1380.72	0	450	0.08	2077.56	646.33	−7835.72
13	2921.69	2600.30	3682.72	3277.61	1404.70	0	450	0.08	2082	600.08	−7235.63
14	2930.37	2666.64	3662.47	3324.78	1428.36	0	450	0.08	2086.5	557.16	−6678.47
15	2939.00	2703.88	3642.32	3372.62	1436.12	0	450	0.08	2104.85	521.68	−6156.79
16	2947.59	2770.73	3622.29	3421.15	1459.27	0	450	0.08	2109.68	484.44	−5672.35
17	2956.13	2837.88	3602.37	3470.38	1482.12	0	450	0.08	2114.61	449.89	−5222.46
18	2964.62	2905.33	3582.56	3520.32	1504.67	0	450	0.08	2119.67	417.83	−4804.62
19	2973.06	2973.06	3562.85	3570.98	1526.94	0	450	0.08	2124.85	388.08	−4416.54
20	2981.46	3041.09	3543.26	3622.36	1548.91	0	450	0.08	2130.18	360.48	−4056.06
21	2989.81	3109.40	3523.77	3674.49	1570.60	0	450	0.08	2135.68	334.87	−3721.19
22	2998.12	3178.01	3504.39	3727.37	1591.99	0	450	0.08	2141.36	311.11	−3410.08
23	3006.38	3246.89	3485.11	3781.00	1613.11	0	450	0.08	2147.22	289.06	−3121.02
24	3014.59	3316.05	3465.95	3835.41	1633.95	0	450	0.08	2153.3	268.61	−2852.41
25	3022.76	3415.72	3446.88	3890.60	1669.28	0	450	0.08	2144.16	247.38	−2605.03

Table A3. NPV results of the PV installation for the net-billing system based on hourly prices, at a 30% self-consumption level.

System Lifetime [Year]	Electricity that was Purchased Self-Consumption Adjusted [kWh/Year]	Electricity Purchase Costs from the Grid [PLN/Year]	Electricity that has been Sold [kWh/Year]	Costs of Selling Electricity to the Grid [PLN/Year]	Savings Related to the Production of Electricity for Own Use [PLN/Year]	Investment Outlays [PLN]	Operating Costs [PLN]	Discount Rate [-]	Investor Cash flow [PLN/Year]	NPV [PLN]	Investment Profitability [PLN]
0	-	-	-	-	-	19,660	-	-	-	−19,660.00	−19,660.00
1	3150	2205.00	4271.00	2797.96	945.00	0	450	0.08	1537.96	1007.37	−18,652.63
2	3150	2236.50	4240.08	2832.90	958.50	0	450	0.08	1554.90	947.28	−17,705.35
3	3150	2299.50	4209.34	2868.25	985.50	0	450	0.08	1554.25	876.59	−16,828.76
4	3150	2331.00	4178.76	2903.99	999.00	0	450	0.08	1571.99	824.70	−16,004.07
5	3150	2394.00	4148.35	2940.14	1026.00	0	450	0.08	1572.14	763.71	−15,240.36
6	3150	2425.50	4118.11	2976.69	1039.50	0	450	0.08	1590.69	718.83	−14,521.53
7	3150	2488.50	4088.04	3013.66	1066.50	0	450	0.08	1591.66	666.15	−13,855.38
8	3150	2520.00	4058.13	3051.04	1080.00	0	450	0.08	1611.04	627.27	−13,228.11
9	3150	2583.00	4028.38	3088.83	1107.00	0	450	0.08	1612.83	581.71	−12,646.40
10	3150	2646.00	3998.80	3127.05	1134.00	0	450	0.08	1615.05	539.65	−12,106.76
11	3150	2677.50	3969.39	3165.71	1147.50	0	450	0.08	1635.71	508.53	−11,598.23
12	3150	2740.50	3940.13	3204.78	1174.50	0	450	0.08	1638.78	472.08	−11,126.15
13	3150	2803.50	3911.03	3244.28	1201.50	0	450	0.08	1642.28	438.40	−10,687.75
14	3150	2866.50	3882.10	3284.23	1228.50	0	450	0.08	1646.23	407.27	−10,280.48
15	3150	2898.00	3853.32	3324.61	1242.00	0	450	0.08	1668.61	384.16	−9896.32
16	3150	2961.00	3824.70	3365.43	1269.00	0	450	0.08	1673.43	357.11	−9539.21
17	3150	3024.00	3796.24	3406.71	1296.00	0	450	0.08	1678.71	332.08	−9207.13
18	3150	3087.00	3767.94	3448.44	1323.00	0	450	0.08	1684.44	308.92	−8898.22
19	3150	3150.00	3739.79	3490.62	1350.00	0	450	0.08	1690.62	287.47	−8610.75
20	3150	3213.00	3711.79	3533.25	1377.00	0	450	0.08	1697.25	267.59	−8343.15
21	3150	3276.00	3683.96	3576.36	1404.00	0	450	0.08	1704.36	249.18	−8093.97
22	3150	3339.00	3656.27	3619.92	1431.00	0	450	0.08	1711.92	232.12	−7861.85
23	3150	3402.00	3628.73	3663.94	1458.00	0	450	0.08	1719.94	216.29	−7645.56
24	3150	3465.00	3601.35	3708.45	1485.00	0	450	0.08	1728.45	201.61	−7443.95
25	3150	3559.50	3574.12	3753.44	1525.50	0	450	0.08	1719.44	185.36	−7258.59

Table A4. NPV results of the PV installation for the discount system, at a 50% self-consumption level.

System Lifetime [Year]	Electricity Demand [kWh/Year]	Electricity Price [PLN/kWh]	Electricity Costs without a PV System [PLN/Year]	Electricity Needed from Grid (after Self-consumption) [kWh/rok]	Electricity to be Picked up from the Grid [kWh/rok]	Difference of Electricity [kWh/rok]	Electricity Cost for Purchase from the Grid [PLN/Year]	Investment Outlays [PLN]	Operating Costs [PLN]	Discount rate [-]	Investor Cash Flow [PLN/year]	NPV [PLN]	Investment Profitability [PLN]
0	-	-	-	-	-	-	-	19,660	-	-	-	−19,660.00	−19,660.00
1	4500	0.70	3150.00	1689.50	2248.40	558.90	0	0	450	0.08	3150.00	2500.00	−17,160.00
2	4500	0.71	3213.00	1704.96	2236.03	531.07	0	0	450	0.08	3213.00	2368.83	−14,791.17
3	4500	0.73	3277.26	1720.33	2223.74	503.41	0	0	450	0.08	3277.26	2244.37	−12,546.80
4	4500	0.74	3342.81	1735.62	2211.50	475.88	0	0	450	0.08	3342.81	2126.30	−10,420.50
5	4500	0.76	3409.66	1750.83	2199.34	448.52	0	0	450	0.08	3409.66	2014.30	−8406.21
6	4500	0.77	3477.85	1765.95	2187.24	421.30	0	0	450	0.08	3477.85	1908.06	−6498.15
7	4500	0.79	3547.41	1780.98	2175.22	394.24	0	0	450	0.08	3547.41	1807.31	−4690.84
8	4500	0.80	3618.36	1795.94	2163.25	367.32	0	0	450	0.08	3618.36	1711.77	−2979.07
9	4500	0.82	3690.73	1810.81	2151.35	340.54	0	0	450	0.08	3690.73	1621.17	−1357.90
10	4500	0.84	3764.54	1825.6	2139.52	313.92	0	0	450	0.08	3764.54	1535.27	177.37
11	4500	0.85	3839.83	1840.31	2127.76	287.45	0	0	450	0.08	3839.83	1453.84	1631.21
12	4500	0.87	3916.63	1854.94	2116.05	261.12	0	0	450	0.08	3916.63	1376.65	3007.86
13	4500	0.89	3994.96	1869.49	2104.41	234.93	0	0	450	0.08	3994.96	1303.48	4311.34
14	4500	0.91	4074.86	1883.95	2092.84	208.89	0	0	450	0.08	4074.86	1234.12	5545.46
15	4500	0.92	4156.36	1898.34	2081.33	182.99	0	0	450	0.08	4156.36	1168.4	6713.86
16	4500	0.94	4239.49	1912.65	2069.88	157.23	0	0	450	0.08	4239.49	1106.11	7819.97
17	4500	0.96	4324.27	1926.88	2058.50	131.62	0	0	450	0.08	4324.27	1047.10	8867.07
18	4500	0.98	4410.76	1941.03	2047.18	106.15	0	0	450	0.08	4410.76	991.18	9858.25
19	4500	1.00	4498.98	1955.11	2035.92	80.81	0	0	450	0.08	4498.98	938.20	10,796.44
20	4500	1.02	4588.96	1969.11	2024.72	55.61	0	0	450	0.08	4588.96	888.01	11,684.45
21	4500	1.04	4680.73	1983.02	2013.58	30.56	0	0	450	0.08	4680.73	840.46	12,524.91
22	4500	1.06	4774.35	1996.87	2002.51	5.64	0	0	450	0.08	4774.35	795.42	13,320.33
23	4500	1.08	4869.84	2010.64	1991.49	−19.14	20.71	0	450	0.08	4849.12	749.24	14,069.57
24	4500	1.10	4967.23	2024.33	1980.54	−43.78	48.33	0	450	0.08	4918.91	704.74	14,774.31
25	4500	1.13	5066.58	2037.94	1969.65	−68.29	76.89	0	450	0.08	4989.69	662.88	15,437.19

Table A5. NPV results of the PV installation for the net-billing system based on monthly prices, at a 50% self-consumption level.

System Lifetime [year]	Electricity that was Purchased Self-Consumption Adjusted [kWh/Year]	Electricity Purchase Costs from the Grid [PLN/Year]	Electricity that has been Sold [kWh/Year]	Costs of Selling Electricity to the Grid [PLN/Year]	Savings Related to the Production of Electricity for Own Use [PLN/Year]	Investment Outlays [PLN]	Operating Costs [PLN]	Discount Rate [-]	Investor Cash Flow [PLN/Year]	NPV [PLN]	Investment Profitability [PLN]
0	-	-	-	-	-	19,660	-	-	-	−19,660.00	−19,660
1	1689.50	1182.65	2810.50	1972.29	1967.35	0	450	0.08	2756.99	2136.10	−17,523.90
2	1704.96	1210.52	2795.04	2000.67	1984.48	0	450	0.08	2774.62	1992.99	−15,530.91
3	1720.33	1255.84	2779.67	2029.46	2029.16	0	450	0.08	2802.78	1867.71	−13,663.20
4	1735.62	1284.36	2764.38	2058.66	2045.64	0	450	0.08	2819.94	1741.98	−11,921.22
5	1750.83	1330.63	2749.18	2088.28	2089.37	0	450	0.08	2847.03	1631.38	−10,289.84
6	1765.95	1359.78	2734.06	2118.33	2105.22	0	450	0.08	2863.78	1521.09	−8768.75
7	1780.98	1406.97	2719.02	2148.82	2148.03	0	450	0.08	2889.87	1423.64	−7345.11
8	1795.94	1436.75	2704.07	2179.74	2163.25	0	450	0.08	2906.24	1327.03	−6018.08
9	1810.81	1484.86	2689.19	2211.10	2205.14	0	450	0.08	2931.38	1241.31	−4776.77
10	1825.60	1533.50	2674.40	2242.92	2246.50	0	450	0.08	2955.91	1160.72	−3616.05
11	1840.31	1564.26	2659.70	2275.20	2260.74	0	450	0.08	2971.68	1081.51	−2534.55
12	1854.94	1613.79	2645.07	2307.94	2301.21	0	450	0.08	2995.35	1010.79	−1523.75
13	1869.49	1663.84	2630.52	2341.15	2341.16	0	450	0.08	3018.47	944.42	−579.33
14	1883.95	1714.39	2616.05	2374.84	2380.61	0	450	0.08	3041.05	882.15	302.82
15	1898.34	1746.47	2601.66	2409.01	2393.53	0	450	0.08	3056.07	821.54	1124.36
16	1912.65	1797.89	2587.35	2443.68	2432.11	0	450	0.08	3077.9	767.06	1891.42
17	1926.88	1849.80	2573.12	2478.84	2470.20	0	450	0.08	3099.23	716.00	2607.42
18	1941.03	1902.21	2558.97	2514.52	2507.79	0	450	0.08	3120.1	668.19	3275.61
19	1955.11	1955.11	2544.90	2550.70	2544.90	0	450	0.08	3140.49	623.42	3899.03
20	1969.11	2008.49	2530.90	2587.40	2581.51	0	450	0.08	3160.43	581.52	4480.55
21	1983.02	2062.34	2516.98	2624.64	2617.66	0	450	0.08	3179.96	542.32	5022.87
22	1996.87	2116.68	2503.14	2662.41	2653.32	0	450	0.08	3199.05	505.66	5528.54
23	2010.64	2171.49	2489.37	2700.71	2688.51	0	450	0.08	3217.74	471.39	5999.92
24	2024.33	2226.76	2475.68	2739.58	2723.24	0	450	0.08	3236.06	439.36	6439.28
25	2037.94	2302.87	2462.06	2779.00	2782.13	0	450	0.08	3258.26	410.06	6849.34

Table A6. NPV results of the PV installation for the net-billing system based on hourly prices, at a 50% self-consumption level.

System Lifetime [Year]	Electricity that was Purchased Self-Consumption Adjusted [kWh/Year]	Electricity Purchase Costs from the Grid [PLN/Year]	Electricity that has been Sold [kWh/Year]	Costs of Selling Electricity to the Grid [PLN/Year]	Savings Related to the Production of Electricity for Own Use [PLN/Year]	Investment Outlays [PLN]	Operating Costs [PLN]	Discount Rate [-]	Investor Cash Flow [PLN/Year]	NPV [PLN]	Investment Profitability [PLN]
0	-	-	-	-	-	19,660	-	-	-	−19,660.00	−19,660.00
1	2250	1575.00	4271.00	2251.75	1575.00	0	450	0.08	2251.75	1668.28	−17,991.72
2	2250	1597.50	3339.58	2275.77	1597.50	0	450	0.08	2275.77	1565.30	−16,426.42
3	2250	1642.50	3308.84	2299.97	1642.50	0	450	0.08	2299.97	1468.57	−14,957.85
4	2250	1665.00	3278.26	2324.34	1665.00	0	450	0.08	2324.34	1377.70	−13,580.15
5	2250	1710.00	3247.85	2348.90	1710.00	0	450	0.08	2348.90	1292.36	−12,287.79
6	2250	1732.50	3217.61	2373.63	1732.50	0	450	0.08	2373.63	1212.21	−11,075.58
7	2250	1777.50	3187.54	2398.54	1777.50	0	450	0.08	2398.54	1136.95	−9938.63
8	2250	1800.00	3157.63	2423.61	1800.00	0	450	0.08	2423.61	1066.28	−8872.35
9	2250	1845.00	3127.88	2448.86	1845.00	0	450	0.08	2448.86	999.93	−7872.42
10	2250	1890.00	3098.30	2474.28	1890.00	0	450	0.08	2474.28	937.63	−6934.79
11	2250	1912.50	3068.89	2499.87	1912.50	0	450	0.08	2499.87	879.16	−6055.64
12	2250	1957.50	3039.63	2525.63	1957.50	0	450	0.08	2525.63	824.26	−5231.37
13	2250	2002.50	3010.53	2551.55	2002.50	0	450	0.08	2551.55	772.74	−4458.64
14	2250	2047.50	2981.60	2577.64	2047.50	0	450	0.08	2577.64	724.38	−3734.26
15	2250	2070.00	2952.82	2603.89	2070.00	0	450	0.08	2603.89	679.00	−3055.26
16	2250	2115.00	2924.20	2630.30	2115.00	0	450	0.08	2630.30	636.41	−2418.85
17	2250	2160.00	2895.74	2656.87	2160.00	0	450	0.08	2656.87	596.45	−1822.40
18	2250	2205.00	2867.44	2683.61	2205.00	0	450	0.08	2683.61	558.96	−1263.45
19	2250	2250.00	2839.29	2710.49	2250.00	0	450	0.08	2710.49	523.78	−739.66
20	2250	2295.00	2811.29	2737.52	2295.00	0	450	0.08	2737.52	490.78	−248.88
21	2250	2340.00	2783.46	2764.71	2340.00	0	450	0.08	2764.71	459.83	210.95
22	2250	2385.00	2755.77	2792.04	2385.00	0	450	0.08	2792.04	430.80	641.75
23	2250	2430.00	2728.23	2819.51	2430.00	0	450	0.08	2819.51	403.56	1045.31
24	2250	2475.00	2700.85	2847.13	2475.00	0	450	0.08	2847.13	378.03	1423.33
25	2250	2542.50	2673.62	2874.89	2542.50	0	450	0.08	2874.89	354.08	1777.41

Table A7. NPV results of PV installation for the net-billing system based on hourly prices, at a 50% self-consumption level, with energy storage.

System Lifetime [Year]	Electricity that was Purchased Self-Consumption Adjusted [kWh/Year]	Electricity Purchase Costs from the Grid [PLN/year]	Electricity that has been Sold [kWh/Year]	Costs of Selling Electricity to the Grid [PLN/Year]	Savings Related to the Production of Electricity for Own Use [PLN/Year]	Investment Outlays [PLN]	Operating Costs [PLN]	Discount Rate [-]	Investor Cash flow [PLN/year]	NPV [PLN]	Investment Profitability [PLN]
0	-	-	-	-	-	19,660	-	-	-	−34,660.00	−34,660.00
1	2250	1575.00	3356.10	2243.43	1575.00	0	450	0.08	3537.70	2858.98	−31,801.02
2	2250	1597.50	3325.18	2267.28	1597.50	0	450	0.08	3587.44	2689.85	−29,111.17
3	2250	1642.50	3294.44	2291.31	1642.50	0	450	0.08	3637.87	2530.63	−26,580.54
4	2250	1665.00	3263.86	2315.52	1665.00	0	450	0.08	3689.01	2380.77	−24,199.76
5	2250	1710.00	3233.45	2339.89	1710.00	0	450	0.08	3740.85	2239.70	−21,960.07
6	2250	1732.50	3203.21	2364.44	1732.50	0	450	0.08	3793.42	2106.92	−19,853.14
7	2250	1777.50	3173.14	2389.17	1777.50	0	450	0.08	3846.73	1981.96	−17,871.18
8	2250	1800.00	3143.23	2414.06	1800.00	0	450	0.08	3900.77	1864.34	−16,006.84
9	2250	1845.00	3113.48	2439.11	1845.00	0	450	0.08	3955.56	1753.65	−14,253.19
10	2250	1890.00	3083.90	2464.34	1890.00	0	450	0.08	4011.11	1649.49	−12,603.70
11	2250	1912.50	3054.49	2489.73	1912.50	0	450	0.08	4067.44	1551.46	−11,052.25
12	2250	1957.50	3025.23	2515.29	1957.50	0	450	0.08	4124.55	1459.22	−9593.03
13	2250	2002.50	2996.13	2541	2002.50	0	450	0.08	4182.45	1372.41	−8220.62
14	2250	2047.50	2967.20	2566.88	2047.50	0	450	0.08	4241.16	1290.74	−6929.87
15	2250	2070.00	2938.42	2592.91	2070.00	0	450	0.08	4300.67	1213.89	−5715.98
16	2250	2115.00	2909.80	2619.11	2115.00	0	450	0.08	4361.03	1141.59	−4574.39
17	2250	2160.00	2881.34	2645.45	2160.00	0	450	0.08	4422.21	1073.56	−3500.82
18	2250	2205.00	2853.04	2671.96	2205.00	0	450	0.08	4484.25	1009.57	−2491.26
19	2250	2250.00	2824.89	2698.61	2250.00	0	450	0.08	4547.15	949.36	−1541.90
20	2250	2295.00	2796.89	2725.4	2295.00	0	450	0.08	4610.91	892.72	−649.18
21	2250	2340.00	2769.06	2752.35	2340.00	0	450	0.08	4675.57	839.43	190.25
22	2250	2385.00	2741.37	2779.43	2385.00	0	450	0.08	4741.11	789.31	979.56
23	2250	2430.00	2713.83	2806.65	2430.00	0	450	0.08	4807.57	742.16	1721.72
24	2250	2475.00	2686.45	2834.01	2475.00	0	450	0.08	4874.95	697.81	2419.53
25	2250	2542.50	2659.22	2861.51	2542.50	0	450	0.08	4943.27	656.10	3075.63

Table A8. NPV results of the PV installation for the discount system, at a 60% self-consumption level.

System Lifetime [Year]	Electricity Demand [kWh/Year]	Electricity Price [PLN/kWh]	Electricity Costs without a PV System [PLN/Year]	Electricity Needed from Grid (after Self-consumption) [kWh/rok]	Electricity to be Picked up from the Grid [kWh/rok]	Difference of Electricity [kWh/rok]	Electricity Cost for Purchase from the Grid [PLN/Year]	Investment Outlays [PLN]	Operating Costs [PLN]	Discount rate [-]	Investor Cash flow [PLN/year]	NPV [PLN]	Investment Profitability [PLN]
0	-	-	-	-	-	-	-	19,660	-	-	-	−19,660.00	−19,660.00
1	4500	0.70	3150.00	1127.40	1798.72	671.32	0	0	450	0.08	3150.00	2500.00	−17,160.00
2	4500	0.71	3213.00	1145.95	1788.83	642.87	0	0	450	0.08	3213.00	2368.83	−14,791.17
3	4500	0.73	3277.26	1164.40	1778.99	614.59	0	0	450	0.08	3277.26	2244.37	−12,546.80
4	4500	0.74	3342.81	1182.74	1769.20	586.46	0	0	450	0.08	3342.81	2126.30	−10,420.50
5	4500	0.76	3409.66	1200.99	1759.47	558.48	0	0	450	0.08	3409.66	2014.30	−8406.21
6	4500	0.77	3477.85	1219.13	1749.80	530.66	0	0	450	0.08	3477.85	1908.06	−6498.15
7	4500	0.79	3547.41	1237.18	1740.17	503.00	0	0	450	0.08	3547.41	1807.31	−4690.84
8	4500	0.80	3618.36	1255.12	1730.60	475.48	0	0	450	0.08	3618.36	1711.77	−2979.07
9	4500	0.82	3690.73	1272.97	1721.08	448.11	0	0	450	0.08	3690.73	1621.17	−1357.90
10	4500	0.84	3764.54	1290.72	1711.62	420.90	0	0	450	0.08	3764.54	1535.27	177.37
11	4500	0.85	3839.83	1308.37	1702.20	393.84	0	0	450	0.08	3839.83	1453.84	1631.21
12	4500	0.87	3916.63	1325.92	1692.84	366.92	0	0	450	0.08	3916.63	1376.65	3007.86
13	4500	0.89	3994.96	1343.38	1683.53	340.15	0	0	450	0.08	3994.96	1303.48	4311.34
14	4500	0.91	4074.86	1360.74	1674.27	313.53	0	0	450	0.08	4074.86	1234.12	5545.46
15	4500	0.92	4156.36	1378.01	1665.06	287.05	0	0	450	0.08	4156.36	1168.40	6713.86
16	4500	0.94	4239.49	1395.18	1655.90	260.72	0	0	450	0.08	4239.49	1106.11	7819.97
17	4500	0.96	4324.27	1412.26	1646.80	234.54	0	0	450	0.08	4324.27	1047.10	8867.07
18	4500	0.98	4410.76	1429.24	1637.74	208.50	0	0	450	0.08	4410.76	991.18	9858.25
19	4500	1.00	4498.98	1446.13	1628.73	182.61	0	0	450	0.08	4498.98	938.20	10796.44
20	4500	1.02	4588.96	1462.93	1619.77	156.85	0	0	450	0.08	4588.96	888.01	11,684.45
21	4500	1.04	4680.73	1479.62	1610.87	131.24	0	0	450	0.08	4680.73	840.46	12,524.91
22	4500	1.06	4774.35	1496.24	1602.01	105.77	0	0	450	0.08	4774.35	795.42	13,320.33
23	4500	1.08	4869.84	1512.76	1593.19	80.43	0	0	450	0.08	4869.84	752.77	14,073.10
24	4500	1.10	4967.23	1529.19	1584.43	55.24	0	0	450	0.08	4967.23	712.36	14,785.46
25	4500	1.13	5066.58	1545.53	1575.72	30.19	0	0	450	0.08	5066.58	674.10	15,459.56

Table A9. NPV results of the PV installation for the net-billing system based on monthly prices, at a 60% self-consumption level.

System Lifetime [Year]	Electricity that was Purchased Self-Consumption Adjusted [kWh/Year]	Electricity Purchase Costs from the Grid [PLN/year]	Electricity that has been Sold [kWh/Year]	Costs of Selling Electricity to the Grid [PLN/Year]	Savings Related to the Production of Electricity for Own Use [PLN/Year]	Investment Outlays [PLN]	Operating Costs [PLN]	Discount Rate [-]	Investor Cash flow [PLN/year]	NPV [PLN]	Investment Profitability [PLN]
0	-	-	-	-	-	19,660	-	-	-	−19,660.00	−19,660.00
1	1127.40	789.18	2248.40	1577.83	2360.82	0	450	0.08	3149.47	2499.51	−17,160.49
2	1145.95	813.63	2236.03	1600.53	2381.37	0	450	0.08	3168.28	2330.49	−14,830.00
3	1164.40	850.01	2223.74	1623.57	2434.99	0	450	0.08	3208.55	2189.83	−12,640.18
4	1182.74	875.23	2211.50	1646.93	2454.77	0	450	0.08	3226.47	2040.79	−10,599.39
5	1200.99	912.75	2199.34	1670.63	2507.25	0	450	0.08	3265.12	1915.92	−8683.47
6	1219.13	938.73	2187.24	1694.67	2526.27	0	450	0.08	3282.20	1784.77	−6898.70
7	1237.18	977.37	2175.22	1719.05	2577.63	0	450	0.08	3319.32	1674.22	−5224.48
8	1255.12	1004.10	2163.25	1743.79	2595.90	0	450	0.08	3335.60	1559.00	−3665.48
9	1272.97	1043.84	2151.35	1768.88	2646.16	0	450	0.08	3371.21	1461.33	−2204.15
10	1290.72	1084.20	2139.52	1794.34	2695.80	0	450	0.08	3405.93	1369.17	−834.98
11	1308.37	1112.11	2127.76	1820.16	2712.89	0	450	0.08	3420.94	1274.19	439.21
12	1325.92	1153.55	2116.05	1846.35	2761.45	0	450	0.08	3454.25	1193.03	1632.23
13	1343.38	1195.61	2104.41	1872.92	2809.39	0	450	0.08	3486.70	1116.59	2748.82
14	1360.74	1238.27	2092.84	1899.87	2856.73	0	450	0.08	3518.33	1044.65	3793.47
15	1378.01	1267.77	2081.33	1927.21	2872.23	0	450	0.08	3531.68	971.47	4764.94
16	1395.18	1311.47	2069.88	1954.94	2918.53	0	450	0.08	3562.00	908.36	5673.31
17	1412.26	1355.77	2058.50	1983.07	2964.23	0	450	0.08	3591.54	849.06	6522.37
18	1429.24	1400.65	2047.18	2011.61	3009.35	0	450	0.08	3620.31	793.37	7315.73
19	1446.13	1446.13	2035.92	2040.56	3053.87	0	450	0.08	3648.31	741.09	8056.82
20	1462.93	1492.18	2024.72	2069.92	3097.82	0	450	0.08	3675.55	692.04	8748.86
21	1479.62	1538.81	2013.58	2099.71	3141.19	0	450	0.08	3702.09	646.05	9394.90
22	1496.24	1586.01	2002.51	2129.92	3183.99	0	450	0.08	3727.90	602.94	9997.84
23	1512.76	1633.78	1991.49	2160.57	3226.22	0	450	0.08	3753.01	562.55	10,560.40
24	1529.19	1682.11	1980.54	2191.66	3267.89	0	450	0.08	3777.45	524.74	11,085.13
25	1545.53	1746.45	1969.65	2223.20	3338.55	0	450	0.08	3815.31	491.40	11,576.53

Table A10. NPV results of the PV installation for the net-billing system based on hourly prices, at a 60% self-consumption level.

System Lifetime [Year]	Electricity that was Purchased Self-Consumption Adjusted [kWh/Year]	Electricity Purchase Costs from the Grid [PLN/Year]	Electricity that has been Sold [kWh/Year]	Costs of Selling Electricity to the Grid [PLN/Year]	Savings Related to the Production of Electricity for Own Use [PLN/Year]	Investment Outlays [PLN]	Operating Costs [PLN]	Discount Rate [-]	Investor cash flow [PLN/Year]	NPV [PLN]	Investment Profitability [PLN]
0	-	-	-	-	-	19,660	-	-	-	−19,660.00	−19,660.00
1	1800	1260.00	2921.10	1952.08	1890.00	0	450	0.08	2582.08	1974.15	−17,685.85
2	1800	1278.00	2890.18	1970.11	1917.00	0	450	0.08	2609.11	1851.09	−15,834.76
3	1800	1314.00	2859.44	1988.20	1971.00	0	450	0.08	2645.20	1742.62	−14,092.14
4	1800	1332.00	2828.86	2006.34	1998.00	0	450	0.08	2672.34	1633.49	−12,458.65
5	1800	1368.00	2798.45	2024.53	2052.00	0	450	0.08	2708.53	1537.12	−10,921.53
6	1800	1386.00	2768.21	2042.78	2079.00	0	450	0.08	2735.78	1440.43	−9481.10
7	1800	1422.00	2738.14	2061.07	2133.00	0	450	0.08	2772.07	1354.90	−8126.20
8	1800	1440.00	2708.23	2079.39	2160.00	0	450	0.08	2799.39	1269.30	−6856.90
9	1800	1476.00	2670.94	2091.85	2214.00	0	450	0.08	2829.85	1190.52	−5666.38
10	1800	1512.00	2643.18	2111.58	2268.00	0	450	0.08	2867.58	1119.81	−4546.57
11	1800	1530.00	2619.49	2134.59	2295.00	0	450	0.08	2899.59	1050.59	−3495.99
12	1800	1566.00	2590.23	2153.04	2349.00	0	450	0.08	2936.04	987.24	−2508.75
13	1800	1602.00	2561.13	2171.51	2403.00	0	450	0.08	2972.51	927.52	−1581.23
14	1800	1638.00	2532.20	2190.00	2457.00	0	450	0.08	3009.00	871.24	−709.99
15	1800	1656.00	2503.42	2208.49	2484.00	0	450	0.08	3036.49	815.37	105.38
16	1800	1692.00	2474.80	2227.00	2538.00	0	450	0.08	3073.00	765.63	871.01
17	1800	1728.00	2446.34	2245.50	2592.00	0	450	0.08	3109.50	718.78	1589.79
18	1800	1764.00	2418.04	2264.01	2646.00	0	450	0.08	3146.01	674.67	2264.46
19	1800	1800.00	2389.89	2282.50	2700.00	0	450	0.08	3182.50	633.15	2897.62
20	1800	1836.00	2361.89	2300.97	2754.00	0	450	0.08	3218.97	594.08	3491.69
21	1800	1872.00	2334.06	2319.43	2808.00	0	450	0.08	3255.43	557.31	4049.01
22	1800	1908.00	2306.37	2337.85	2862.00	0	450	0.08	3291.85	522.73	4571.74
23	1800	1944.00	2278.83	2356.24	2916.00	0	450	0.08	3328.24	490.21	5061.95
24	1800	1980.00	2251.45	2374.59	2970.00	0	450	0.08	3364.59	459.63	5521.58
25	1800	2034.00	2224.22	2392.90	3051.00	0	450	0.08	3409.90	432.20	5953.77

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