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PROSUMER DILEMMA: DOES CHOOSING NET BILLING LOWER HOUSEHOLD ELECTRICITY COSTS?

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ABSTRACT

Aim: The study generates information about the expected electricity costs under several scenarios including PV panel and storage battery additions using the case of a rural prosumer operating a micro-PV installation and faced with a decision to switch to the new net-billing (NB) system or continue with net-metering (NM) (given the new subsidy for a storage battery). **Methods**: The benchmark data about prosumer electricity production and use and predicted electricity prices for the 15-year period serve to calculate future changes in electricity costs under alternative scenarios, including a household without a micro-PV installation. The prosumer cost for electricity used is calculated using the Levelized Cost of Electricity (LCOE) and the modified LCOEC accounting for consumption (LCOEC). **Results**: The average electricity price is estimated at 2.33 PLN/kWh in 2037 (almost three times more than in 2022). A similar increase is calculated for prices using the G12 tariff applied to households. The prosumer flexibility in electricity self-consumption determines the advantage of a storage battery, but the subsidy for a micro-PV installation is crucial. Without the subsidy, having a micro-PV installation with a storage battery in the NB system would not lower the LCOEC as compared to the NB scenario without storage. **Conclusions**: The NB system is associated with higher electricity bills than the NM system, although owning a micro-PV installation still lowers electricity costs as compared to a household without it. The adoption of micro-PV installations by households is likely to continue, albeit at a slower rate than in recent years.

Key words: prosumer, micro-PV installation, net-billing, net-metering, electricity generation

JEL codes: Q28, Q42, Q47

INTRODUCTION

Electricity and fossil fuel prices have increased since the spring of 2020 [Nyga-Łukaszewska and Aruga 2020, Chomać-Pierzecka et al. 2022a, b, Zasuń and Derski 2022] and the Russian-Ukrainian war further affected energy markets [Michiyuki and Shunsuke 2023, European Council and Council of the European Union 2023, Antosiewicz et al. 2022]. Higher fossil fuel prices translated into a substantial electricity price increase in Poland, where coal accounts for 83% of domestic energy production [Polskie Sieci Elektroenergetyczne 2022]. Efforts to protect households from sudden electricity price increases included freezing rates for a limited volume of consumed electricity [Dz.U. 2022 poz. 2127, Dz.U. 2022 poz. 2243]. The anticipated termination of the electricity rate freeze in the summer of 2024, the continuing threat of energy

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insecurity, and the welfare-affecting higher electricity prices are increasing household interest in becoming a prosumer, i.e., a producer of electricity from renewable energy sources (RES) with the option to supply the excess to the grid.

The EU climate policy implementation encompassing the GHG emission reduction, air quality improvement, and reduction of fossil fuel use have been driving household adoption of renewable energy source (RES) utilization for space heating [Klepacka et al. 2018, Klepacka and Florkowski 2019, 2021] and micro-PV installations [Siudek et al. 2020] in Poland. The invasion of Ukraine by Russia and the EU-imposed sanctions on energy imports from Russia propelled the already rising energy prices, dramatically increasing household electricity bills. The unexpected invasion coincided with revisions in EU regulations stemming from the drive to further lower emissions and changes in the pricing of electricity in all member countries.

The revised "Poland's Energy Policy until 2040" (PEP2040) [M.P. 2021 poz. 264] lists the acceleration of RES development [Kancelaria Prezesa Rady Ministrów 2022] to reduce dependence on imported fossil fuels and increase energy security. A larger share of RES in Poland's energy mix could insulate households from electricity bill increases. The Levelized Cost of Electricity (LCOE) generated by solar farms is already lower than that of power plants using fossil fuels [International Renewable Energy Agency 2022]. In Poland, the PV sector has been the fastest developing RES since 2018 [Instytut Energetyki Odnawialnej 2022] and the annual growth rate of installed PV capacity was three times higher than the average in the European Union (EU) in 2022 [Instytut Energetyki Odnawialnej 2023].

The growth rate was due to household investment in micro-PV equipment, which accounted for 75% of the installed PV capacity in the first quarter of 2022. The growth was spurred by the government's "My Electricity" (Mój Prąd or My Electricity) program that targets household installations of 2kW–10kW PV capacity. By early 2023, the program accepted another 413,000 applications totaling 2.38GW of PV capacity [Ministerstwo Klimatu i Środowiska 2023] and subsidized prosumer investment costs. Besides sheltering households from electricity price increases, the program supports the national goal of a 23% RES share in electricity consumption by 2030 and the climate policy goal of reducing CO_2 emissions associated with electricity generation by 30% compared to 1990 [M.P. 2021 poz. 264].

In April 2023, the government announced yet another subsidy program ("My Electricity 5.0 – MP5") for micro-PV and heat pump installations. The program incentivizes household self-consumption of generated electricity to reduce supply to the grid. The new government subsidy program requires a prosumer to adopt the new net billing (NB) settlement system, implying the termination of prosumer participation in the existing net-metering system (NM) [Ministerstwo Klimatu i Środowiska 2022]. The NB system effectively lowers the rate paid for the electricity a prosumer supplies to the grid [Dz.U. 2015 poz. 478].

The two decades of implementing the energy and climate policy in the EU ultimately affect households. The considered case is placed in the context of historical institutionalism and its recent applications to the shift in feed-in tariffs. The replacement by the EU of the feed-in tariffs with an auctioning system will introduce competitiveness to the electricity market that involves prosumers. The effort seems an afterthought following years of EU-designed programs promoting the utilization of RE by offering generous subsidies that created the uncompetitive environment in the first place. The current study examines the case of a prosumer household already operating a micro-PV installation subsidized by earlier editions of the "My Electricity" program, offsetting a large portion of the investment but facing the possible choice between two billing systems due to this new wave of regulatory changes. The household is composed of three adults residing in a detached house in the predominantly rural Mazursko-Warmińskie Voivodeship in north-eastern Poland. The average per capita income in the Mazursko-Warmińskie Voivodeship is 70.9% of the national average [Chinowski 2023] and influences the households' ability to self-finance investments in micro-PV equipment. The region also typically receives less solar radiation than other regions [Lorenc 2005], limiting the volume of generated electricity. A review of the regional distribution of the "My Electricity" program funds does not overlap with the most favorable solar radiation conditions. The Mazursko-Warmińskie Voivodship received only 2.4% of the available funds, placing it 13th among all 17 voivodeships [Instytut Energetyki Odnawialnej 2023]. The area has a low density of grid connections and piped heat from a central power station is unavailable, which motivated households to invest in PV equipment to operate a heat pump to secure heating of the living space and other electricity uses. The prosumer considered in this study is only one of two micro-PV installation operators in the area and, as a result, currently faces a low risk of being disconnected because of the grid's inability to store oversupplied electricity during sunny weather.

The current case study complements earlier research on the use of net-metering (NM) and net-billing (NB) settlement systems in Poland and other EU countries [Trela and Dubel 2022, Kurz and Nowak 2023] following recent regulatory changes and the implementation of the new billing options. The current case illustrates a choice of a prosumer who has already invested in micro-PV equipment: Would they switch from the NM to the NB system, settling for the electricity supplied and purchased from the grid? Under Poland's climatic conditions, especially for prosumers residing in a region with less than average solar radiation, the need to heat the living space is a common driver of investment in equipment utilizing solar radiation. The study accounts for the most recent changes using projected electricity prices. Because the prosumer has already invested in micro-PV equipment, the pre-investment considerations are omitted. However, the provided scenarios include the expansion of the already owned PV installation and the addition of a storage battery. The frequent and abrupt changes in the law and regulations affecting RES utilization, especially the use of solar radiation, poses the risk of slowing micro-PV installation expansion [Instytut Energetyki Odnawialnej 2022]. The regulatory uncertainty discouraged household investment in RE utilization in the past [Klepacka and Pawlik 2018, Trela and Dubel 2022, Kurz and Nowak 2023].

The EU energy policy has been intertwined with the domestic energy policy of Germany, especially since 2014. The explanation of the energy transformation initiated in Germany has been interpreted in the context of historical institutionalism [Leiren and Reimer 2018]. The feed-in tariff underlying the NM system benefited early investors in household-installed micro-PV equipment. Those households benefited from the long-term (multi-year) contracts paying for electricity supplied to the grid. Those early investors in Germany, as those later in Poland, also received generous subsidies for the purchase and installation of PV panels on the roofs of their detached houses. But, as noted in the literature, the early prosumer-households burdened the non-participants with the maintenance fees because they did not pay for access to the grid. Under the concept of institutional change, those who did not benefit from the system would push for a change. The theory of gradual institutional change suggests gradual displacement, as those who benefit from the system (here the NM system) are unable to thwart the shift to new rules (here the NB system) [Mahoney and Thelen 2010].

The NM system encouraged households to become prosumers in order to utilize RE that would not have been economically feasible otherwise due to the inherit risks, such as the seasonality of solar radiation in Poland and northern Europe. Once the number of prosumers grew, the subsidy scheme costs rose, making it unsustainable, leading to auctioning and the NB system. Although it has been argued that the NM system (feed-in tariff) was not competitive, therefore justifying the auctioning system, the actual operating system is not truly competitive. A description of the system being implemented in Poland is provided later in this paper.

Coincidentally, the fundamental change in the EU and Germany's energy policy took place in the year of the Ukraine Crimea region's annexation by Russia. The feed-in tariffs offering prosumers above-the-market prices for electricity generated from RES in Germany were replaced in 2016 by the auctioning system following a pilot program started in 2014 [Leiren and Reimer 2018]. The auctioning system replaces the direct participation of households, reflecting participatory democracy by favoring large corporations, which are the key players in the new system. Households, as small providers of electricity, are placed at a disadvantage and further constrained by the 50 kW size of a household PV installation. The 2014 European Commission decision changed the guidelines recommending the auctioning system, which is incompatible with the NM (feed-in tariff) system. Since the change of the system has not occurred under demands from non-prosumer households burdened with their electricity purchase bill but also grid access fees, the theory of gradual institutional change does not fully capture the realities. As rightly noted by Leiren and Reimer (2018), the EU has been the external force, an endogenous change-agent, imposing the change from the top down. Table 1 shows the selected documents originating from various European institutions within the EU and links some of them to specific events ("critical junctures" [Leiren and Reimer 2018]) such as the annexation of Crimea and the invasion of Ukraine, giving weight to the distinctly different policy change explanation emphasizing triggering events as disruptive to the period of stability and offering an opportunity for a change.

The list of documents in Table 1 illustrates why the process of increasing the utilization of RE can be viewed as chaotic from the household perspective. Each of the listed documents required EU-member countries to develop or later modify their domestic policies, all eventually affecting households through their electricity bills. The case study in this paper is an illustration of a path of adapting to the rapidly changing regulatory regime affecting the access, availability, and cost of an essential household good: electricity.

Background: recent geopolitical events, solar radiation utilization, and tariff systems

In the case of Poland, household electricity consumption initially increased, driven by COVID-19-imposed restrictions forcing remote work and schooling in 2020. The unprecedented interest in investing in micro-PV installations recently has been driven by the advance of energy prices, including electricity prices, since 2021. The 2022 Russian invasion of Ukraine resulted in elimination of natural gas imports from Russia, increasing domestic natural gas prices. Natural gas was used primarily for cooking and heat-

Table 1. Timeline of major policy decisions affecting household electricity use

Directive/Document	Date	Stated goal(s)
European Parliament Directive 2012/27 changing directives from 2009 and 2010 and annulment parliament directives from 2004 and 2006[1]	December 2012	Reduce energy by 20% by 2020
European Parliament "Clean energy for all Europeans"[2]	December 2016	Primary and final energy use reduced to 32.5% by 2030 using forecast from 2007
European Parliament[3]	July 2021	"Fit for 55" revised energy efficiency goal for 2030 using 2020 forecast
European Parliament[4]	May 2022	Further revision in additional reduction of energy efficiency; increased support for solar radiation utilization
European Parliament[5]	May 2022	Revised share of RE to 42.5% by 2030 (desired level, 45%)
European Parliament Directive[6]	October 2023	Revised goal of primary and final use to 11.7% by 2030 using forecast from 2020
European Parliament, several documents[7]	December 2024	10- year energy and climate national plan for the period 2021–2030; Poland's target of RE share is 23.8% in 2030

Source: [1] Directive 2012/27/EU; [2] Communication from the Commission… COM/2016/0860 final; [3] Communication from the Commission… COM/2021/550 final; [4] Communication from the Commission… COM/2022/230 final; [5] Communication from the Commission… COM/2022/221 final; [6] Directive (EU) 2023/1791; [7] Ministerstwo Klimatu i Środowiska, 2024.

ing water, and, to a lesser degree, for heating the living space for households with access to piped gas [GUS 2023]. Only 1.9% of households used electricity as the main space heating source in 2021 (before the start of the Russia-Ukraine war) because of the already high cost of this energy type [GUS 2023]. Coal, in various forms, was the most common energy type used in space heating, often with the addition of biomass. The start of the war increased the prices of all energy types in Poland and coincided with the implementation of the new EU electricity pricing regulations as well as the continuation of the "My Electricity" program and the planned new version of the program for 2023. In the first half of 2023, household electricity bills increased by about 30% [Derski 2023]. The increase in electricity prices changed the expectations of prosumers who had invested in micro-PV installations.

The past EU policy and support programs for solar energy utilization subsidized thermal solar panel installations [Kaya et al. 2018] and required local governments to initiate the application and recruit the households planning to invest in thermal panels. Individual households were excluded from early programs. Solar farms producing electricity suffered from low profitability, while changes in the law created uncertainty [Klepacka and Pawlik 2018]. The PV panels were installed by public entities and businesses off-grid because regulations were lacking. Since 2016, the regulation stimulated the adoption of micro-PV panels rather than earlier installed thermal panels used to heat water. The early PV-support adopters, applying for investment grants through local governments, were enabled to supply the grid with unrestricted volumes of electricity.

The effects of regulations on the electricity billing systems were subject to earlier studies. Trela and Dubel [2022] conducted a sensitivity analysis on the return of two alternative space heating and electricity supply systems in a detached house accounting for the NM and NB systems. The study conducted before the implementation of the NB system in April 2022 was motivated by the perceptions of the new system's benefits vs. the NM system operating at that time. Their study compared the return on investment in a natural gas-fired boiler and the purchase of electricity from the grid and an air/water heat pump powered by electricity from PV panels. The combination of a micro-PV installation and an air/water heat pump, with an investment subsidy, offers an alternative, especially in areas lacking piped heat or natural gas. The study omitted storage batteries because of the negligible presence of such technology in prosumer households at the time the study was conducted and the inadequate regulations [Adamska 2021]. The authors concluded that the regulatory changes in billing systems introduced in 2021 would reduce the rate of return and new investments in the PV installations.

Kurz and Nowak [2023] noted that the boom of investment in micro-PV installations by households in Poland was instrumental in reaching the installed capacity of RES-utilizing equipment by mid-2022, set originally for 2040 under EU policy. The strong household response in the utilization of solar radiation to increasing electricity and energy prices prompted the decision to change the billing system from NM to the NB forced by the EU regulations. The change slowed household decisions to invest in additional micro-PV equipment [Kurz and Nowak 2023].

An energy netting study of Danish households was motivated by the 80% share of taxes in the final electricity bill [Ziras et al. 2021]. The NM system introduced in Denmark in 2010 led on the one hand to a decrease in tax revenues, and on the other hand was unfair to households without capabilities to generate their own electricity but bearing the cost of grid access fees. The study viewed the NB system as a special case of the NM system, where the netting, i.e., the calculation of the balance between electricity supplied and purchased from the grid, is performed in very short intervals. The study focused on a case of a typical prosumer with a 6 kW PV system and showed that the NB increased self-consumption, reduced purchase from the grid, and, under Danish conditions, generated slight annual savings.

The continuously rising electricity prices negatively impact consumers and encourage simulations exploring the economic benefits of operating a micro-PV and battery storage system (BSS) [Chatzigeorgiu et al. 2023]. BSS assures household energy security and reduces electricity bills. It also limits the frequency with which the grid is accessed, improving its performance [Chatzigeorgiu et al. 2020], especially in countries with favorable solar radiation conditions like those in the Mediterranean region. Chatzigeorgiu et al. [2023] indicate that the consideration of NB shows intercountry discrepancies. The existence of differences across countries limits universal applicability of the results and warrants the examination of country-specific cases.

The "My Electricity 5.0" program subsidizes the purchase of batteries for storing the electricity generated by micro-PV installations in Poland. Storage reduces the risk of disconnecting the household from the grid in periods of oversupply of electricity. Storage also increases the flexibility of self-consumption and lowers purchases from the grid. The average living space of a rural house in Poland is about 63% larger than the living space of an average urban household, implying greater heating needs. The average electricity consumption is also nearly 55% higher in rural households [GUS 2023], which also commonly use more outside lights than urban households, increasing their utility bills.

The current study uses real data from a prosumer operating in a substantially changed environment of accelerated electricity price increase since 2021, an elevated risk of energy supply due to the Russian invasion in Ukraine in 2022, and the emerging system of electricity trading exchange using the readings of remotely read electricity meters. The study considers a case of a prosumer located in northeastern Poland, where solar radiation is less intense than in EU countries located in southern Europe.

Prosumer-targeting settlement systems

The difference between the NM and NB systems is the compensation households receive for sending surplus electricity to the grid. The NM system allows the prosumer to access 0.8 kW for every 1k W supplied to the grid. The remaining 0.2k W compensates the grid operator for the prosumer's access to the grid. The agreement between a prosumer and the distributor is valid for 15 years and the prosumer purchases electricity at the existing tariff without paying the distribution fee. Prosumers using the NM system have incentives to supply an unlimited amount of electricity to the grid above their own use. Under exceptionally sunny weather, which seldom covers the whole country, the prosumer-supplied electricity causes grid instability, leading to an automatic disconnection of some, especially in areas of dense detached housing operating micro-PV installations.

A prosumer using the NB system sells surplus electricity to the grid and creates a deposit used to balance the purchased electricity. The prosumer is compensated for 20% of any net balance injected into the grid accrued in the preceding 12 months. The intentionally small share is to discourage installations of micro-PV equipment capable of generating electricity exceeding the volume a household typically uses. Still, the NB system incentivizes supplying electricity when demand is high and purchasing when demand is low in response to changing prices. The NB system requires users to pay distribution fees only for the purchased electricity, not for the volume supplied to the grid. From July 1, 2022, until June 30, 2024, the surplus is set at the price for the month it was supplied (RCEm). Ultimately, the NB system will use the hourly market price (RCE) once the Central Energy Market Information System (CEMIS) starts to operate on July 1, 2024 (Centralny System Informacji Rynku Energii – CSIRE) [Ministerstwo Klimatu i Środowiska 2021a].

CEMIS processes energy market information available to all market participants, including prosumers. CEMIS collects meter readings on the volume supplied and purchased by each prosumer every hour from the mandatory remote electricity meters [Dz.U. 2021 poz. 1093, Centrum Informacji Rynku Energii 2023]. The payments for electricity sent or purchased are calculated using the meter readings [Ministerstwo Klimatu i Środowiska 2021] allowing a prosumer to manage electricity use in response to hourly price fluctuations [Ministerstwo Klimatu i Środowiska 2021b]. CEMIS shortens the period of approving the sale of electricity to a single day, verifies the electricity volume a prosumer sent or obtained from the grid, and facilitates access to electricity market price information [Polskie Sieci Elektroenergetyczne 2023a].

Electricity market: the prosumer perspective

Contrary to intentions [International Renewable Energy Agency 2019], electricity pricing was not yet market-driven in 2023 or the first half of 2024 in Poland. The government implemented the "Wprowadzenie Rządowej Tarczy Solidarnościowej" program to protect households from electricity price volatility. The retained 2022 rates applied to three levels of annual volume of electricity used: 2,000 kWh, 2,600 kWh, and 3,000 kWh [Serwis Samorządowy PAP 2022]. A price ceiling was implemented if the purchased volume exceeded the 3,000 kWh threshold at 0.693 PLN/kWh [Serwis Rzeczpospolitej Polskiej 2023] and increased the distribution fees [Urząd Regulacji Energetyki 2023b]. In the case of prosumers using the NM system, the limit applied only to the net volume of purchased electricity. For those subject to the NB system, the annual limit applies to the total electricity volume purchased from the grid [Ministerstwo Klimatu i Środowiska 2022b]. Additionally, the 2023 VAT rate for electricity increased to 23% from 5% in 2022 [Redakcja PIT.pl 2022]. Ultimately, the NB system imposes a quasi-market price discovery applicable to prosumer-supplied electricity through CEMIS, but the purchase of electricity from the regional monopoly is at prices subject to the approval of the government agency: Urząd Regulacji Energetyki. Overall, the system has to be recognized as lacking transparency and providing a potential source of uncertainty in the future.

MATERIALS AND METHODS

The prosumer case examined in this study exemplifies households residing in detached houses in rural areas. The study examines the existing PV installation in a three-person household located in northeastern Poland. The installation has 24 PV panels (JA SOLAR 340) and has a capacity of 8.16 kW. The Fronius Symo inverter has a capacity of 7 kW. Data on the volume of electricity generated are from the monitoring system and available at Fronius Solar.web. The data on the volume of electricity sent to the grid, purchased from the grid, and the balance were from the portal of PGE, the electricity supplier contracted by the prosumer. The costs follow the G-12 tariff applied to households. Hourly readings of the volume and direction of electricity flow were obtained from the remote electricity meter (LZO in Polish), an Apator Otus 3 meter.

Calculations are for both systems, i.e., NB and NM, and include two options to increase returns: expansion of PV capacity and storage of surplus electricity in a household battery. For comparison, the third case of a household that does not have a PV installation is also considered. The analysis involves seven scenarios, each for the 15-year period that covers the expected life of the PV panels. The scenarios are: NB – net-billing system; NB+ – enlarged PV installation in the NB system; MNB – original PV capacity with the storage option in the NB system; NM – net-metering system; NM+ – enlarged PV installation in net-metering; MNM – original PV capacity with the storage option in the NM; BPV – household without a PV installation.

The micro-PV installation cost is 4,800 PLN/kW, and the subsidy obtained from "My Electricity 4" is 4,000 PLN/kW. Those costs are the same for both settlement systems. It has been assumed that an additional 19,000 PLN would be obtained from "My Electricity 5," the current program, for the investment in a storage battery and additional PV panels.

The future electricity prices supplied to the grid and purchased cover the period 2023–2037. The benchmark period is from April 1, 2022, to March 31, 2023. Returns from electricity production under the two settlement systems were calculated using the LCOE and LCOEC (the latter accounts also for the electricity consumed).

Fronius Solar.web data indicate that the PV installation in question generated 8,388 kWh between April 1, 2022 and March 31, 2023. The forecast for the next 14 years for the same period as in the benchmark assumes a 0.5% decline in the PV panels' capacity to generate electricity [Instytut Energetyki Odnawialnej 2023]. In scenarios assuming the expansion of the PV installation, the maximum capacity is 10 kW to avoid a reduction of the coefficient used in calculating the surplus sent to the grid, which is 0.8. The installed capacity increased from 8.16 kW to 9.86 kW by adding five PV panels, type JA SOLAR 340 W. The forecast for scenarios NB+ and NM+ starting on April 1, 2023, assumes the electricity generated increases under the scenarios NB and NM by 20.83%, and the annual performance decline begins on April 1, 2024.

The billing of prosumers is based on the hourly balance of electricity consumed and sent to the grid. The balance of the electricity purchased and supplied to the grid was calculated using the vector method [Polska Grupa Energetyczna 2023]. For every hour (*t*) in the 24-hour period, the balance is the difference between the electricity purchased (E_p) and supplied to the grid (E_o) in kWh ($E_{z,t} = E_{p,t} - E_{o,t}$). When the purchase and supply take place during the same hour, the prosumer is free of distribution charges [Fotowoltaikaonline.pl 2023].

Knowing the volume of PV-generated electricity (E_w) and the directions of electricity flows in the benchmark year, the volume of electricity consumed (E_e) in the period (*t*) is:

$$E_{e,t} = E_{w,t} - E_{o,t} + E_{p,t} \tag{1}$$

The prosumer consumption of electricity remains unchanged during the 14-year period. In leap years, February is assumed to have 28 days. The future volume of electricity generated (E_w), the volume purchased from the grid (E_p), supplied (E_o), and consumed (E_a) are obtained using formulas (2)–(5):

$$\begin{gathered} E'_{w,t} \geq E_{e,t} \rightarrow E'_{a,t} = E_{e,t} \\ E'_{w,t} < E_{e,t} \rightarrow E'_{a,t} = E'_{w,t} \end{gathered} \tag{2}$$

$$E'_{p,t} = E_{e,t} - E'_{w,t} \tag{3}$$

$$E'_{o,t} = E'_{w,t} - E_{e,t} \tag{4}$$

$$E'_{z,t} = E'_{p,t} - E'_{o,t} \tag{5}$$

As a result, it is possible to predict the balance (E_z) in the period (*t*), while omitting the situations of simultaneous purchase and supply of electricity.

Market price of electricity

The average electricity price (*CG*) is based on records, s, collected during the 24-hour session (*S*) and weighted by the traded volume (*EG*) [Dziennik Urzędowy Unii Europejskiej 2019]:

$$RCE = \frac{\sum_{s \in S} CG_s \cdot EG_s}{\sum_{s \in S} EG_s} \tag{6}$$

The monthly electricity price used for settlement with prosumers is the average market electricity price (*RCE*) for a given month, *m*, weighted by the volume of prosumer-supplied electricity (*E*). The price applies to the period T when the accounts were not settled [Journal of Laws of 2015 item 478. 2023]:

$$RCEm = \frac{\sum_{t \in T} RCE_t \cdot E_t}{\sum_{t \in T} E_t} \tag{7}$$

Calculation of the LCOE and LCOEC

Formula (1A) shows the calculation of the *LCOE* for the scenarios using the NM system:

$$LCOE_{NM} = \frac{\sum\left(I_t - D_t\right)}{\sum E'_{u,t}} \tag{8}$$

where the definition of $E'_{u,t}$ varies for three scenarios: for NM: $E'_{u,t} = E'_{a,t} + E'_{a,t} + 0.8 \cdot E'_{z-,t}$, for NM+: $E'_{u,t} = E'_{aw,t} + 0.8 \cdot E'_{zw-,t}$, and for *MNM*: $E'_{u,t} = E'_{am,t} + 0.8 \cdot E'_{zm-,t}$. Calculations of the *LCOE* for the scenarios using the *NB* system are made using the following formula (2A):

$$LCOE_{NB} = \frac{\sum\left(I_t - D_t + K_t - Z_t\right)}{\sum E'_{u,t}} \tag{9}$$

where the definition of $E'_{u,t}$ is: for NB: $E'_{u,t} = E'_{a,t} + E'_{z-,t}$, for NB+: $E'_{u,t} = E'_{aw,t} + E'_{zw-,t}$, and for *MNB*: $E'_{u,t} = E'_{am,t} = E'_{am,t} + E'_{zm-,t}$.

The following formula calculates the *LCOEC*:

$$LCOEC = \frac{\sum\left(I_t - D_t + R_t\right)}{\sum E_{e,t}} \tag{10}$$

where R_t is the cost of electricity in year *t* and is a result of the need to balance the electricity supplied to and purchased from the grid [Urząd Regulacji Energetyki 2020, Urząd Regulacji Energetyki 2023a].

Addition of electricity storage

The household was assumed to have a battery capable of storing 50% of the daily electricity consumed [Pomorski et al. 2022]. The average daily electricity consumption was 44.5 kWh, in the benchmark year. A BYD Battery-Box Premium HVM 22.1, with a capacity of 22.08 kW, serves as the model. The battery has 96% efficiency and an annual deterioration rate of 2.2%, and is capable of 6,000 charge-discharge cycles [Instytut Energetyki Odnawialnej 2023].

The battery operation involves charging with electricity (E_{dom}) intended to be supplied to the grid in a given time period (t) until it is fully charged. The volume of electricity discharged (E_{odm}) does not exceed the expected volume of electricity purchased in a given hour, assuming that for every 1 kWh sent to the grid, the volume obtained from the grid is 0.96 kWh. For the MNM and MNB scenarios, it is possible to predict the volume obtained (E_{pm}) or sent to the grid (E_{om}), and the self-consumption (E_{am}) using formulas (9)–(12):

$$E'_{am,t} = E'_{a,t} + E'_{odm,t} \tag{11}$$

$$E'_{pm,t} = E'_{p,t} - E'_{odm,t} \tag{12}$$

$$E'_{om,t} = E'_{o,t} - E'_{dom,t} \tag{13}$$

$$E'_{zm,t} = E'_{pm,t} - E'_{om,t} \tag{14}$$

The approach predicts the electricity volume needed from the grid while accounting for the storage (E_{zm}) in period (t). The prediction ignores the case of simultaneous purchase from and supply to the grid.

Forecast of market price

A series of future electricity prices is calculated to compare each scenario. *RCE* and RCE_m are particularly important in the scenarios using the *NB* system because those prices determine the value of the electricity supplied to the grid. The future prices were based on a series of hourly market prices for every hour from the *PSE* portal for the period January 1, 2018 to June 22, 2023 [Polskie Sieci Elektroenergetyczne 2023B].

Table 2. 24-hour factors in the calculations

Hour	Factor [–]
1	0.86
2	0.82
3	0.81
4	0.80
5	0.81
6	0.84
7	0.96
8	1.01
9	1.08
10	1.09
11	1.06
12	1.06
13	1.06
14	1.05
15	1.01
16	1.02
17	1.06
18	1.11
19	1.15
20	1.20
21	1.16
22	1.04
23	1.01
24	0.90

Source: own calculations based on data from PSE 2023B.

The prices showed a daily pattern and an increasing tendency, especially in the years 2021–2023, in average electricity prices (Fig. 1). The daily pattern showed that the average RCE values increase between 5 a.m. and 8 a.m. and between 2 p.m. and 7 p.m. The prices were set to increase annually with the exception of 2020 COVID-19 related regulations. [Derski 2021].

Seasonality is marked for each hour by averaging earlier described multipliers calculated for each hour (Tab.2). Once the seasonal effects are identified, they can be separated from the market prices by dividing RCE by the seasonality element for each hour.

Next, the calculation of trends allowed the examination of de-seasoned RCE values in relation to time. The calculations were made using the function Analysis ToolPack in Excel. Excel allowed the fitting of variables in the given function, that are statistically the closest to given values. The result was the following trend function: (15)

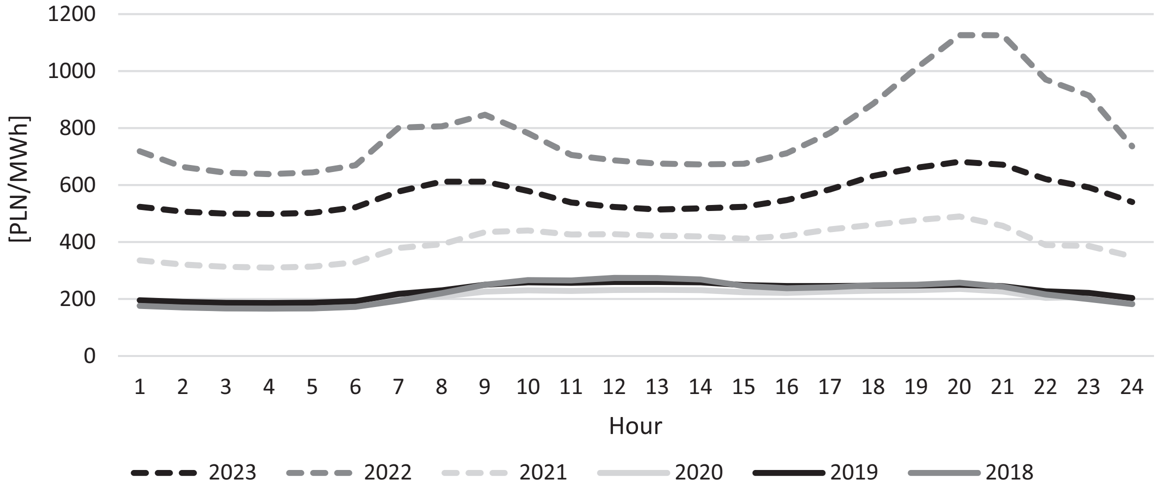

Fig. 1. Average hourly market price of electricity, 2018–2023.

Source: own calculations using data from PSE 2023B.

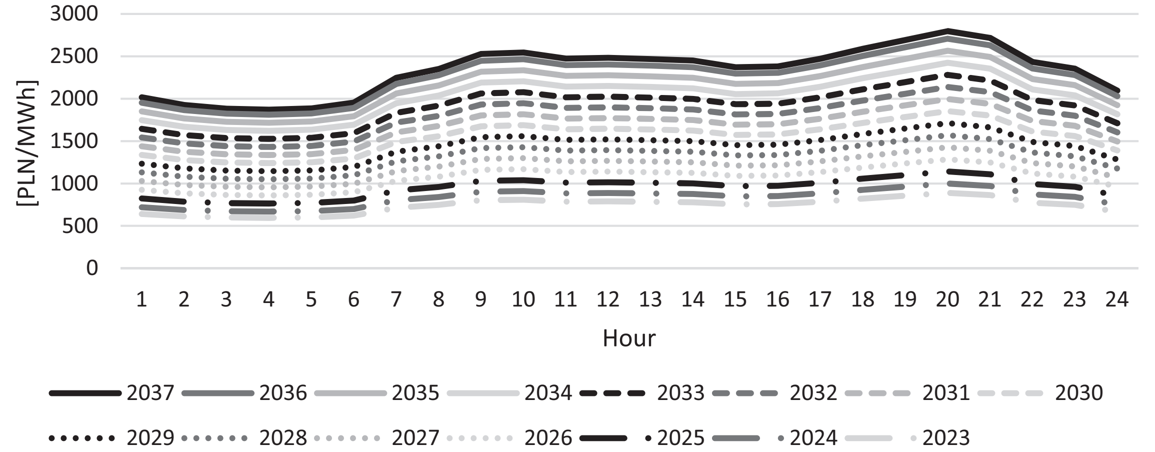

Fig. 2. Calculated average hourly market electricity prices, 2023–2035

Source: own calculations based on data from PSE 2023B.

The forecast was obtained for every hour from June 12, 2023, until March 31, 2037 (Fig. 2), by multiplying the seasonality elements (Tab. 2) by the calculated trend value obtained using formula (15).

$$f(t) = 0.013578 \cdot t + 62.134972 \quad (15)$$

The trend value multiplied by the hourly factor generates the electricity price per hour for the period June 12, 2023, to March 31, 2037 (Fig. 2). Additionally, all scenarios required the RCE_m values from June 2023 to June 2024. The monthly electricity prices resembled the average monthly *RCE* values for the period June 2022 to May 2023 and confirmed the high value of the coefficient of determination, $R^2 = 0.9136$ ($y = 0.6701x + 138.21$). The future monthly RCE_m values were obtained using the calculated trend.

The rates and fees charged by the prosumer's electricity supplier, PGE, are not published. The supplier is assumed to set next year's electricity prices

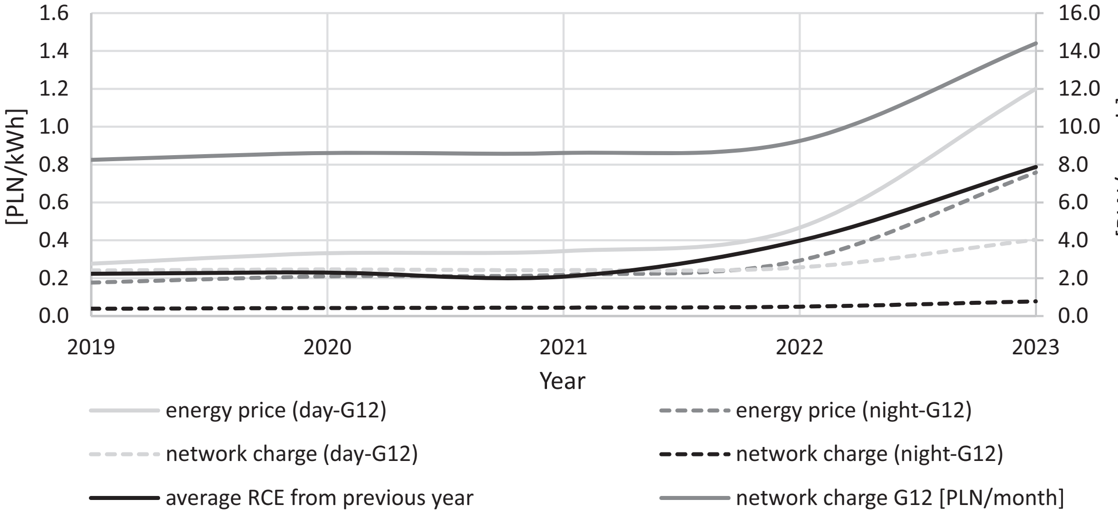

Fig. 3. Comparison of day and night rates and fees for the average RCE value in the preceding year

Source: own calculations based on data from PSE 2023B.

given current electricity market conditions, that is, the hourly records in year *N* influence prices in year *N* + 1 (Fig. 3).

This is a statement with no verb that isn't continued in the rest of the sentence so something is missing. The values of the coefficient of termination are high (R^2 >0.9) (Fig.5). The tariff fees for the preceding years. The future rates and fees are obtained for day and night rates for the G-12 tariff applied to households (Fig. 4) under the assumption of fixed transfer fees, quality fees, subscription fees, as well as *RES* cogeneration capacity fees [Urząd Regulacji Energetyki 2020], and VAT and excise taxes after 2023 because of the inability to estimate them.

The data are for electricity generated annually by micro-PV systems installed in the prosumer household, and its electricity consumption. Also included are data on the amount of electricity sent to the grid and the price of electricity purchased from the grid. The forecast is for the period 2023–2037. Returns from electricity production under two settlement systems were calculated using the *LCOE* and *LCOEC*.

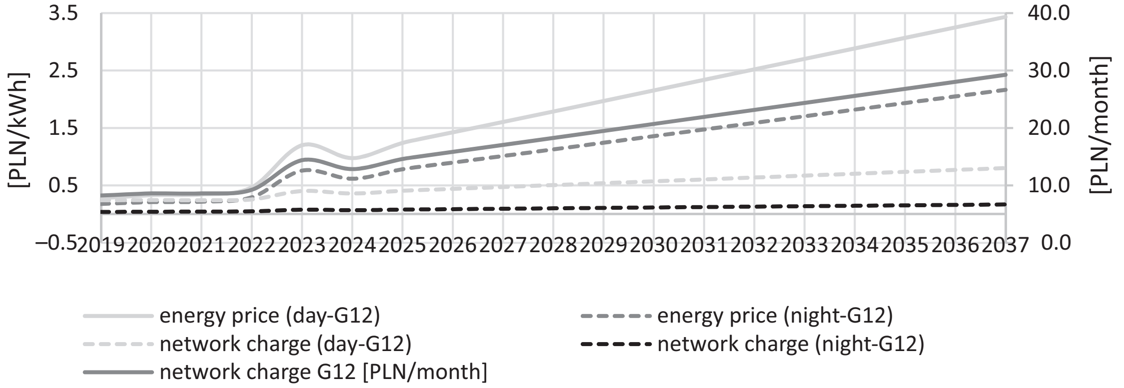

Fig. 4. Predicted rates and fees through the year 2037

Source: own calculations based on data from PSE 2023B.

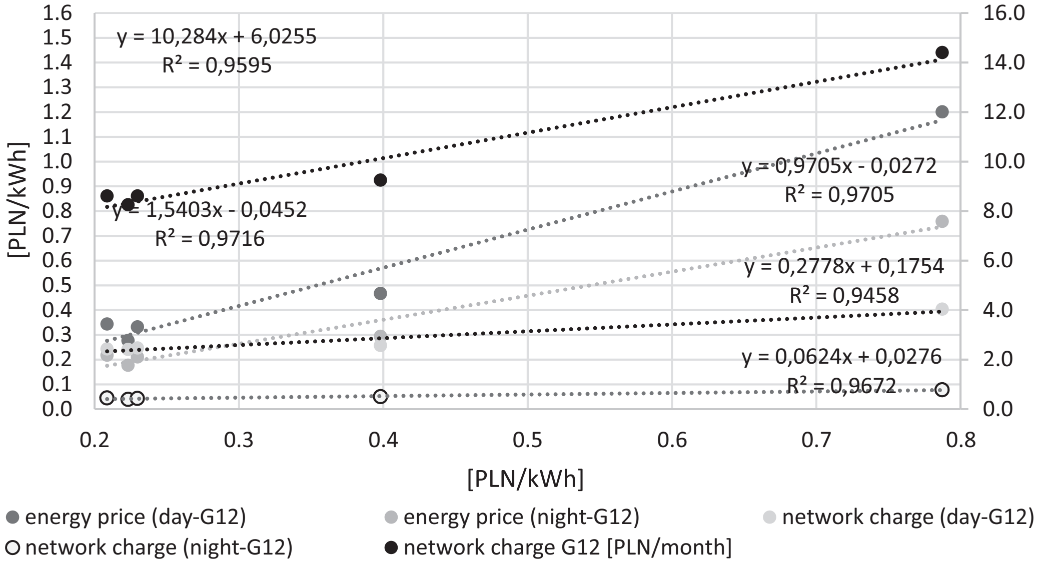

Fig. 5. Trends for day and night rates and fees for the average RCE value in the preceding year

Source: own calculations based on data from PSE 2023B.

Electricity cost calculations for the scenarios

The average cost of electricity generation, the Levelized Cost of Electricity (LCOE), is applied in calculating returns from various types of energy generating electricity [Sulewski et al. 2016]. Here, it is used to compare the returns from the PV installation under the earlier listed scenarios. The LCOE formulas vary across the scenarios because of the differences in the total cost of installation (I_t), amount of subsidy (D_t), and volume of electricity from the prosumer's perspective (Eu'). The formula for scenarios NB, NB+, and *MNB* include earnings from sending electricity to the grid (Z_t) and higher distribution fees (K_t) than in scenarios *NM*, *NM+*, and *NMB*. All calculations assume the constant value of the PLN.

The Levelized Cost of Electricity Consumption (LCOEC) applied in this study accounts for all costs associated with electricity purchased from the grid by the prosumer (R_t) and electricity consumed (E_e) in year *t*. The LCOEC reveals to a potential micro-PV installation investor the expected electricity bill for a period of 15 years under a given settlement system. Also, the average cost of the electricity consumed applies to scenario BPV, where a household does not have a PV installation.

RESULTS AND DISCUSSION

Benchmark period

The total prosumer electricity consumption was 16.26 MWh in the benchmark period and reflects the 8.39 MWh of electricity generated (of which 28% was consumed by the household) and the 13.89 MWH purchased from the grid. The daily pattern of electricity flows between April 1, 2022 and March 31, 2023 are averaged in Fig. 6. The micro-PV installation generated the largest volume of electricity between 11 a.m. and 2 p.m., reflecting the position of the sun and the panels. Self-consumption increases with the presence of household members and the use of home appliances. The volume of purchased electricity increases when the heat pump operates as night temperatures drop. The positive net balances (E_z+) followed the seasonal weather pattern, reflecting the purchase of electricity to supply the heat pump. The largest negative net balances (E_z–) are from May to September, when the prosumer supplied electricity to the grid. Self-consumption peaked in March and April, when the outside temperatures require the heat pump to operate to heat the living space.

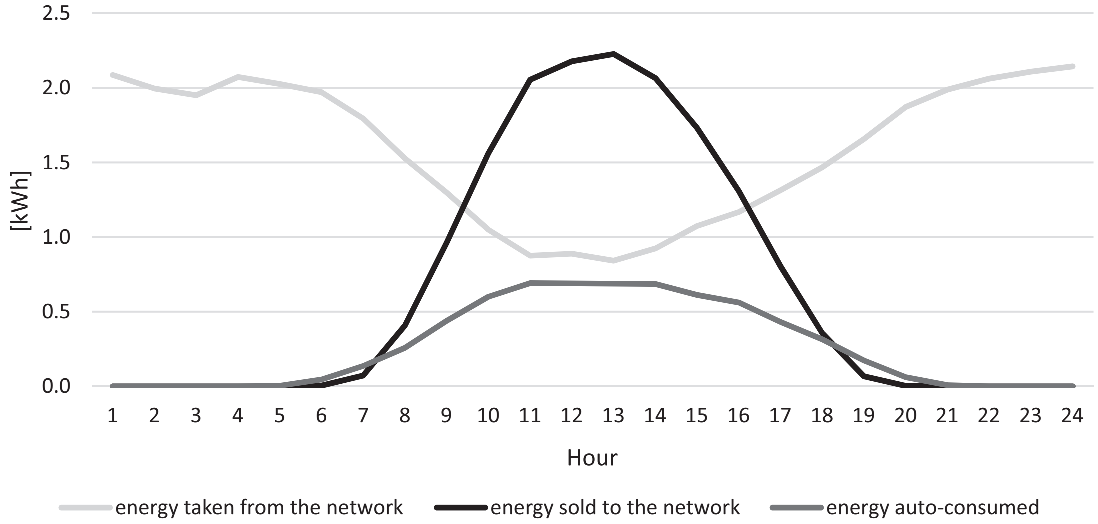

Fig. 6. Average hourly volume of electricity self-consumed, purchased, and supplied to the grid

Source: own calculations.

Scenarios NB and NM

The NB users will pay less per kWh, and the unit cost of electricity rises more slowly during the 15-year period than under the NM system (Fig. 4).

The lower cost per kWh does not imply a lower annual electricity bill (Fig. 8). The prosumer using the NB system will pay more for electricity than the NM user, except in the first three months in 2037, the last year of the 15-year period. As the future calculated electricity prices increase, so do the prices paid to the prosumer for the supplied electricity, but those prices will be lower starting in the second year of the considered period once the system applies the hourly electricity prices.

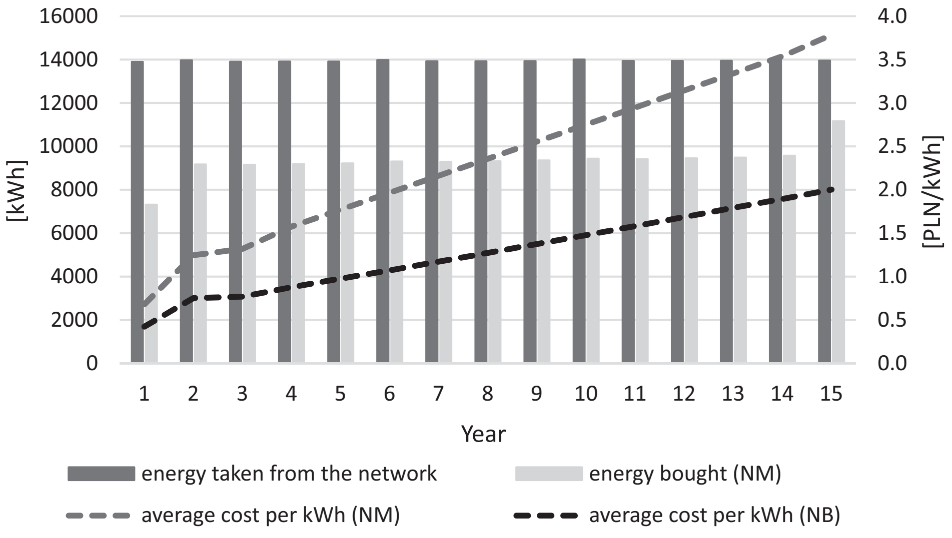

Fig. 7. Expected electricity purchase and the average kWh price in the 15-year period

Source: own calculations.

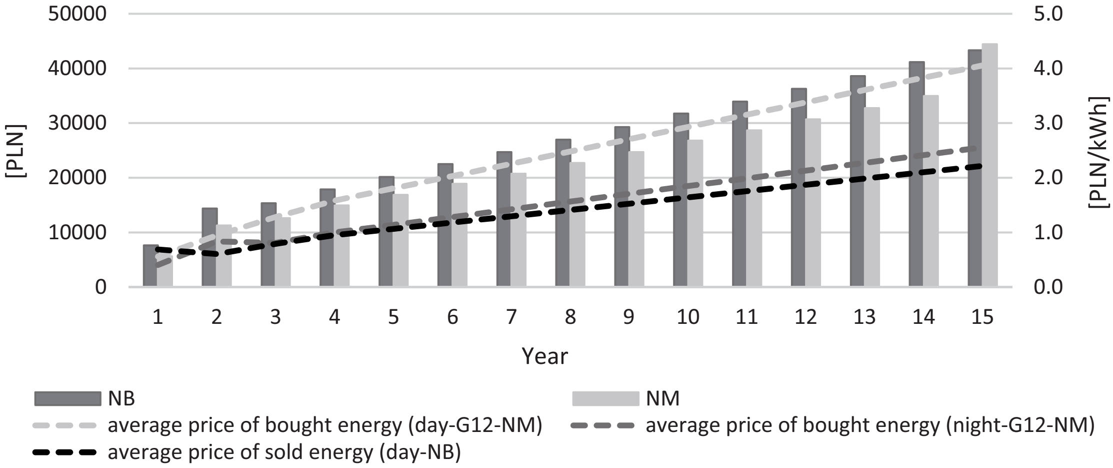

Fig. 8. Annual cost of consumed electricity and average electricity prices for the 15-year period

Source: own calculations.

The LCOE under the NB system is negative because the revenues from sales of surplus electricity average 0.46 PLN/kWh per unit of generated electricity (Table 3). Under the NM system, the LCOE is positive, reflecting the cost of electricity generation of 0.34 PLN/kWh. The LCOEC for scenario NM is lower and in scenario NB, a prosumer will pay about 0.23 PLN/kWh for every unit consumed (Table 3).

Scenarios NB+ and NM+

The flow of electricity changed with the addition of PV panels (Fig. 9). There is a noticeable increase in the volume of electricity sent to the grid after year one (Table 4). The self-consumption share declines from 28% to an average of 25.5% because the volume generated increased, but the self-consumption in hours of the strongest solar radiation remained un-

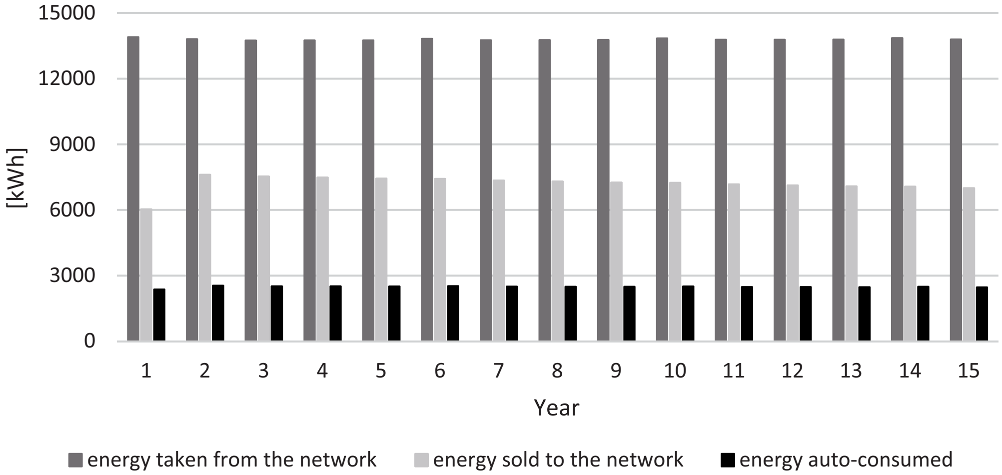

Fig. 9. Volume of the electricity purchased, supplied to the grid, and self-consumed following the addition of PV panels in the 15-year period

Source: own calculations.

Table 3. Calculated LCOE and LCOEC values for NM and NB scenarios for the annual period April 1 – March 31

Year						LCOEC [PLN/kWh]										
				NB				NM				NB				
	I_t [PLN]	D_t [PLN]	$E_{u,t}$ [kWh]	I_t [PLN]	D_t [PLN]	$E_{u,t}$ [kWh]	K_t [PLN]	Z_t [PLN]	I_t [PLN]	D_t [PLN]	E_z [kWh]	R_t [PLN]	I_t [PLN]	D_t [PLN]	E_z [kWh]	R_t [PLN]
1	39,168	4,000	7,181	39,168	4,000	8,388	2,067	4,443	39,168	4,000	16,255	5,622	39,168	4,000	16,255	7,619
2			7,188			8,390	1,902	3,410			16,341	11,275			16,341	14,374
3			7,114			8,304	1,853	4,850			16,255	12,593			16,255	15,332
4			7,080			8,263	2,030	5,997			16,255	14,949			16,255	17,874
5			7,046			8,222	2,168	6,695			16,255	16,864			16,255	20,134
6			7,051			8,224	2,312	7,416			16,341	18,889			16,341	22,514
7			6,979			8,140	2,436	8,066			16,255	20,744			16,255	24,685
8			6,946			8,099	2,569	8,737			16,255	22,703			16,255	26,980
9			6,913			8,058	2,699	9,399			16,255	24,680			16,255	29,285
10			6,917			8,061	2,839	10,096			16,341	26,806			16,341	31,753
11			6,847			7,978	2,953	10,699			16,255	28,684			16,255	33,922
12			6,814			7,938	3,079	11,336			16,255	30,702			16,255	36,260
13			6,781			7,898	3,202	11,963			16,255	32,739			16,255	38,608
14			6,786			7,901	3,337	12,636			16,341	34,964			16,341	41,163
15			6,717			7,820	2,102	13,195			16,255	44,438			16,255	43,329
				–0.46				1.564				1.798				

Source: authors’ calculations.

Table 4. Calculated LCOE and LCOEC values for MNM and MNB scenarios and LCOEC values for BPV scenario for the annual period April 1 – March 31

Year	**LCOEC [PLN/kWh]**								**LCOEC [PLN/kWh]**							
	MNB			MNM					MNB				BPV			
	I_t [PLN]	D_t [PLN]	$E_{u,t}$ [kWh]	I_t [PLN]	D_t [PLN]	$E_{u,t}$ [kWh]	K_t [PLN]	Z_t [PLN]	I_t [PLN]	D_t [PLN]	E_z [kWh]	R_t [PLN]	I_t [PLN]	D_t [PLN]	E_z [kWh]	R_t [PLN]
1	39,168	4,000	7,181	39,168	4,000	8,388	1,835	4,443	39,168	4,000	16,255	6,258	39,168	4,000	16,255	7,619
2	80,000	19,000	7,599	80,000	19,000	8,295	1,092	1,967	80,000	19,000	16,341	11,093	80,000	19,000	16,341	12,962
3			7,518			8,210	1,035	4,043			16,255	12,891			16,255	13,183
4			7,481			8,169	1,133	5,882			16,255	15,221			16,255	14,428
5			7,443			8,128	1,210	6,568			16,255	17,155			16,255	16,274
6			7,449			8,131	1,288	7,260			16,341	19,179			16,341	18,209
7			7,369			8,048	1,360	7,915			16,255	21,073			16,255	20,016
8			7,333			8,008	1,436	8,574			16,255	23,046			16,255	21,921
9			7,296			7,969	1,510	9,225			16,255	25,042			16,255	23,842
10			7,300			7,971	1,585	9,888			16,341	27,160			16,341	25,887
11			7,223			7,890	1,654	10,503			16,255	29,084			16,255	27,736
12			7,187			7,851	1,728	11,129			16,255	31,115			16,255	29,717
13			7,151			7,813	1,800	11,746			16,255	33,170			16,255	31,718
14			7,155			7,815	1,875	12,381			16,341	35,387			16,341	33,885
15			7,078			7,736	1,032	12,958			16,255	42,707			16,255	35,777
	–0.06			1.826					1.758				2.590			

Source: authors' calculations.

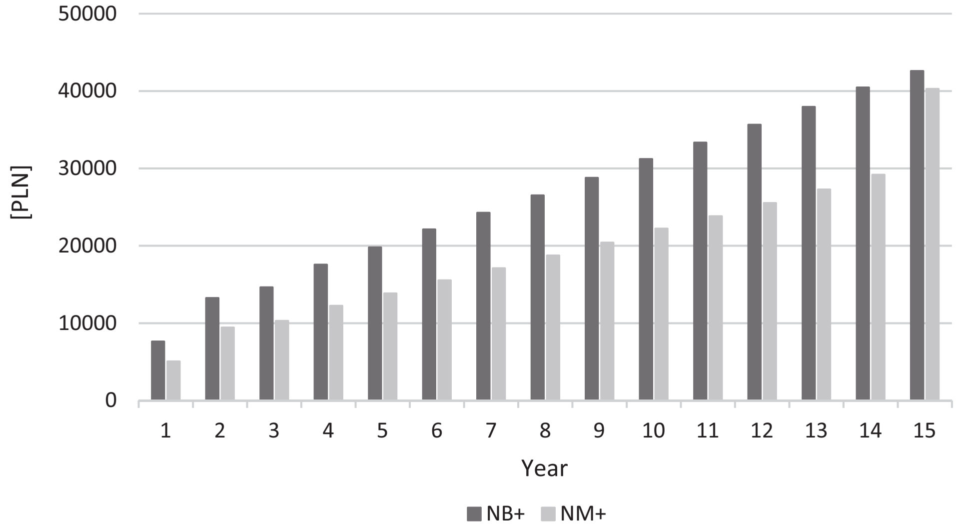

Fig. 10. Annual expenses for the purchased electricity under scenarios NB+ and NM+ following the addition of PV panels

Source: own calculations.

changed. The added capacity of 1.7 kW did not cause a significant decrease in the electricity purchased because the purchase takes place during the 24-hour period when the in the PV installation does not generate electricity.

Fig. 10 shows the costs associated with scenarios NB+ and NM+, which involve the expansion of capacity to 9.86 kW beyond one year after the PV installation. There is a clear advantage of the scenario NM+ over the NB+ regarding lower costs for the electricity consumed. Fig. 10 shows the expenses associated with scenarios NB+ and NM+ one year after the capacity expansion. The NM+ scenario features lower expenses than the NB+.

The LCOE calculations for scenarios increasing the generation of PV electricity involve the added investment of 8,500 PLN. The LCOE for the NB+ scenario is negative because a prosumer earns on average 0.27 PLN/kWh from selling electricity to the grid (Table 5). The LCOE in the NM+ system is positive, reflecting the cost of 0.35 PLN/kWh for the generated electricity. The LCOEC in the NB+ scenario is larger than in the NM+ scenario and the prosumer will pay about 0.43 PLN for every purchased kWh (Table 5).

Scenarios with the storage battery

The LCOEC is used to compare returns from the PV installation with or without storage and for two systems of settlements. The formula for the LCOE calculation varies across the scenarios because of the differences in the total cost of installation (I_t), amount of subsidy (D_t), and the volume of electricity from the prosumer's perspective (E_u'). The formula for scenarios NB, NB+ and MNB include earnings from sending electricity to the grid (Zt), but also additional costs due to higher (than in scenarios NM, NM+ and NMB) distribution fees (K_t).

Scenarios MNB and MNM

Adding a storage battery implies charging it with the prosumer-generated electricity and only once fully charged, sending any excess power to the grid. Electricity is purchased if the battery is empty. The increase in consumption from 28% to 57%, which includes electricity discharged from the battery, lowers the volume purchased and sent to the grid. The largest volume supplied to the grid is around 2 p.m. (Fig. 11), a time of the highest solar radiation and low prosumer electricity needs.

Table 5. Calculated LCOE and LCOEC values for NM+ and NB+ scenarios for the annual period April 1 – March 31

Year	NM+			NB+												
	I_t [PLN]	D_t [PLN]	$E_{u,t}$ [kWh]	I_t [PLN]	D_t [PLN]	$E_{u,t}$ [kWh]	K_t [PLN]	Z_t [PLN]	I_t [PLN]	D_t [PLN]	E_z [kWh]	R_t [PLN]	I_t [PLN]	D_t [PLN]	E_z [kWh]	R_t [PLN]
1	39,168	4,000	7,181	39,168	4,000	8,388	2,257	4,443	39,168	4,000	16,255	5,056	39,168	4,000	16,255	7,619
2	8,500	–	8,625	8,500	–	10,147	2,372	4,320	8,500	–	16,341	9,433	8,500	–	16,341	13,239
3			8,537			10,043	2,350	5,295			16,255	10,297			16,255	14,620
4			8,496			9,993	2,575	5,997			16,255	12,250			16,255	17,558
5			8,455			9,943	2,750	6,695			16,255	13,846			16,255	19,780
6			8,461			9,946	2,934	7,416			16,341	15,538			16,341	22,118
7			8,374			9,844	3,091	8,066			16,255	17,095			16,255	24,253
8			8,334			9,795	3,260	8,737			16,255	18,745			16,255	26,510
9			8,294			9,746	3,426	9,399			16,255	20,416			16,255	28,777
10			8,300			9,748	3,604	10,096			16,341	22,214			16,341	31,199
11			8,215			9,648	3,750	10,699			16,255	23,814			16,255	33,337
12			8,175			9,600	3,911	11,336			16,255	25,535			16,255	35,637
13			8,136			9,552	4,068	11,963			16,255	27,278			16,255	37,946
14			8,141			9,555	4,239	12,636			16,341	29,181			16,341	40,454
15			8,058			9,457	2,700	13,195			16,255	40,271			16,255	42,591
	1.370			1.799												

Source: Authors' calculations.

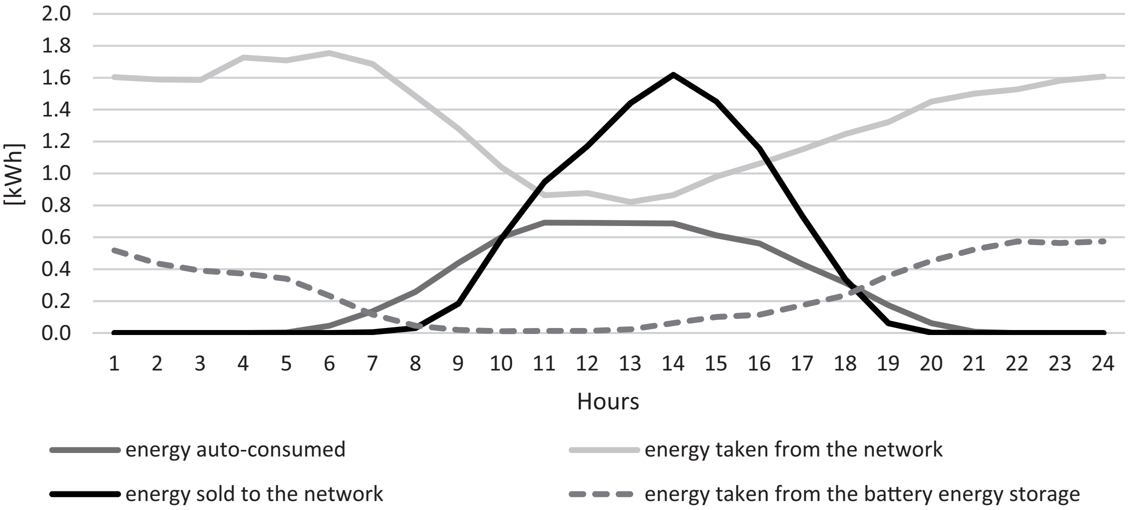

Fig. 11. Average hourly volume of the purchased, supplied, and self-consumed electricity and electricity discharged from the storage battery

Source: own calculations.

Electricity stored in the battery by 7 p.m. is consumed by the household later that evening, when the generation ceases.

The prosumer expenses under scenarios MNB and MNM with a battery added to the existing PV installation are shown in Fig. 12. Under the NB system, the prosumer will pay more in the first two years of using the battery than when using the NM system. Starting in year four, the bill in the MNB scenario is lower than in the MNM scenario.

The advantage of the MNB system over the MNM results from the pricing of the electricity supplied to the grid and the reduced purchases because of the self-consumption. Under the MNB system, the prosumer compensates for a portion of the cost of the electricity obtained from the grid by the revenues from selling their surplus (Fig. 13). Under the MNM system, the prosumer offsets a part of the purchased electricity cost by reducing the volume sent to the grid, as he can only recover up to 80% of the electricity sent. Moreover, in the scenarios involving a storage battery, 4% of generated electricity is used to charge/discharge the battery, which implies a “loss” of 24% of the generated electricity under the MNM scenario.

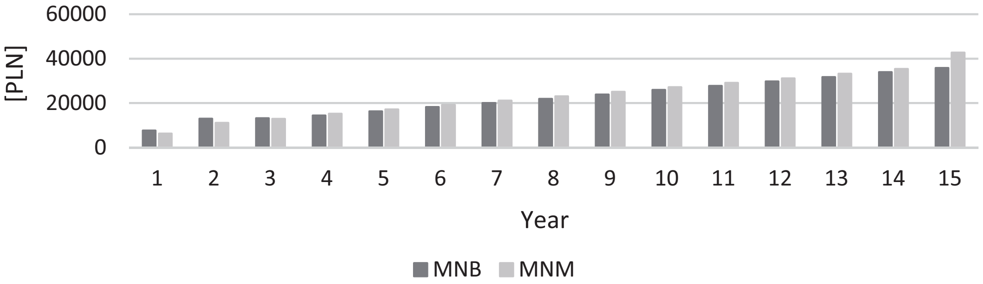

Fig. 12. Annual expenses of purchased, consumed electricity for scenarios MNB and MNM with the addition of a storage battery during the 15-year period.

Source: own calculations.

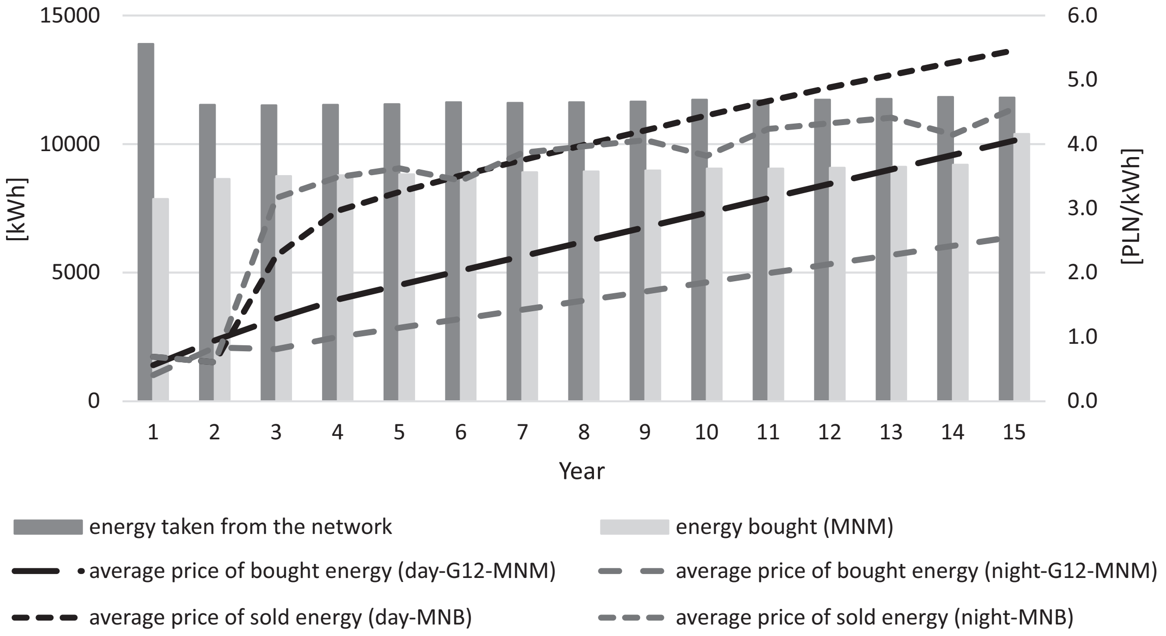

Fig. 13. Annual cost of consumed electricity and the average electricity prices at day- and night-time rates for the 15-year period

Source: own calculations.

The LCOE in the MNB scenario is negative because of the earnings from electricity sales, which implies earnings of an average 0.06 PLN/kWh per unit of electricity generated by the PV installation (Table 6). The LCOEC values under scenario MNM are positive, reflecting the electricity unit costs from the PV installation at 0.88 PLN/kWh. The assumption of additional investment costs is identical for both types of calculated LCOE and LCOEC values. The LCOEC for scenario MNB are lower than for the MNM system and the prosumer pays about 0.07 PLN less for each consumed kWh than under the NM system (Table 6).

BPV scenario

Scenario BPV is for a household that does not operate a micro-PV installation and involves the calculation of consumed electricity for a period of 15 years that a prosumer would have to pay if he did not own PV equipment. The LCOEC in scenario BPV is 2.59 PLN/kWh, assuming constant electricity consumption, and the calculations account for leap years (29 days, not 28 days in February), (Table 6).

Table 6. Calculated LCOEC values for scenario BPV

Year	E_z [kWh]	R_t [PLN]
1	16,255	14,120
2	16,341	21,016
3	16,255	23,954
4	16,255	28,376
5	16,255	31,892
6	16,341	35,602
7	16,255	38,921
8	16,255	42,438
9	16,255	45,954
10	16,341	49,738
11	16,255	52,983
12	16,255	56,501
13	16,255	60,017
14	16,341	63,875
15	16,255	67,045

Note: Each period is from April 1 to March 31.

Source: own calculations.

CONCLUSIONS

The study considered a case of a rural prosumer operating micro-PV installation to supply electricity to the grid and draw it from the grid to operate a heat pump and other uses. With the most recent revisions in the energy sector regulations, the policy to decarbonize the economy, and promotion programs offering new grants for RES utilizations, the prosumer faces the choice between the continued use of the NM settlement system or expanding the micro-PV installation and adding a storage battery under the condition of switching to the NB system. Under the NM settlement system, the prosumer could supply an unlimited volume to the grid, free of access or distribution fees. The fee cost was shifted to non-prosumer households, that is, those whose applications for the grant program were denied or who never considered applying because they could not afford the required matching contribution. An earlier study of Danish prosumers indicated the unfairness of waving the fees.

The NB system is complex because, since the current formula (until June 30, 2024), the price the prosumer receives for the electricity supplied in month N is established in month N+1. Starting July 1, 2024, the prices will be the hourly market prices, which will increase the uncertainty about the value of the household-generated electricity. A potential prosumer will have to manage their own and national electricity consumption patterns and understand the pattern of daily electricity price fluctuations and how electricity demand changes with the seasons.

The calculation of electricity prices through 2037 made it possible to estimate prosumer gains under the NB system. The calculation applied historical data of the electricity hourly market prices. The forecast indicates a steady growth of electricity prices reaching 2.33 PLN/kWh (almost 300% more) in 2037, as compared to 0.79 PLN/kWh in 2022. As the RCE values grow, so do the retail prices established by electricity distributors supplying households. Electricity prices according to the G12 tariff for 2023 for customers of the PGE company equaled 1.2 PLN/kWh during the day and 0.76 PLN/kWh at night and are expected to reach 3.43 PLN/kWh and 2.17 PLN/kWh in 2037, respectively.

Figure 14 shows the summary of the annual electricity costs for the seven scenarios and a 15-year period of operating a PV installation. The results show a prosumer using the NB system for the 15-year period will pay 0.23 PLN/kWh more for every kWh used than under the NM system. Expanding the micro-PV installation capacity when using the NB system will not improve gains from the investment, but for a prosumer using the NM system, the decrease would amount to 0.19 PLN/kWh. It appears that the purpose of the NM system

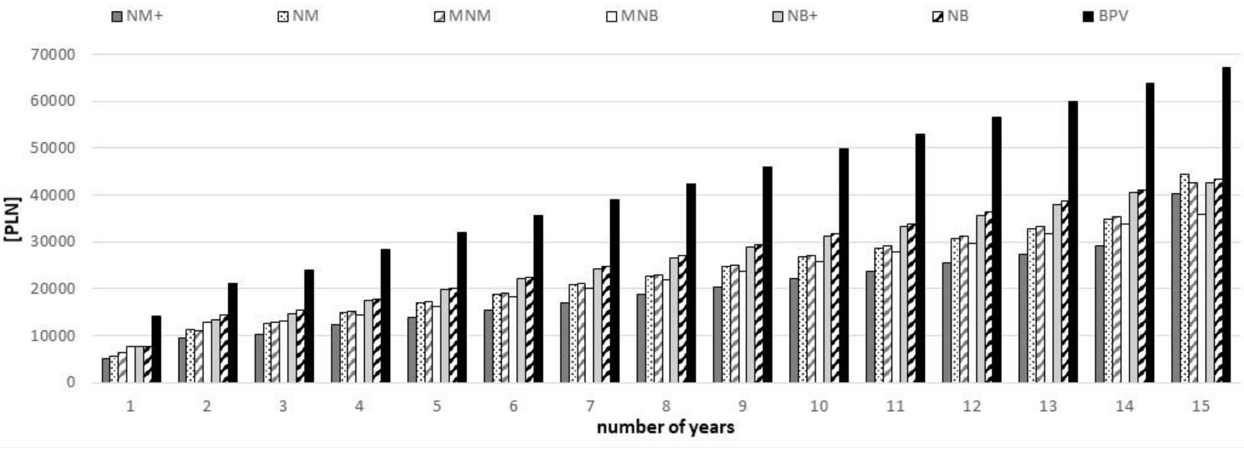

Fig. 14. Annual costs of consumed energy for each scenario for a 15-year period

Source: own calculations.

was to take a portion of the electricity generated by the household to the grid without compensation, discouraging investment in the household storage. However, the storage battery in the NB system increases the gains from the investment by a small amount, lowering the cost of consumed electricity by 0.004 PLN/kWh.

Gains due to electricity storage are linked to the household's pattern of electricity use, and the size of the subsidy because without those factors, the LCOEC in scenario MNB would not have been lower than in scenario NB. Although the settlement conditions have worsened following the introduction of the NB system, it is still worthwhile to invest in RE because the investment in a micro-PV installation can still lower the household electricity bill. A broader question remains how low-income households could benefit from the program. A step in the right direction was the elimination of family per capita income requirements, but the matching funds condition is still at issue. Additionally, since some low-income persons may be cognitively challenged, there is a need to assist low-income households in applying to a program and, later, reporting any grant funding in the mandatory annual tax filing.

Electricity price increases are highly likely in the coming years due to the zero- and low-emission requirements of commercial power generation plants. Any additional shocks like the Russian invasion of Ukraine and the subsequent energy market volatility could further contribute to electricity price increases. Electricity generation is still to a large extent based on fossil fuels in Poland and many power plants are costly to operate because of the high prices of CO_2 emission permits and prices of imported feedstock, which is highly dependent on the geopolitical conditions.

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OPŁACALNOŚĆ MIKROINSTALACJI PV W NOWEJ WERSJI PROSUMENCKIEJ – STUDIUM PRZYPADKU

STRESZCZENIE

Cel: Artykuł generuje informację o oczekiwanych kosztach elektryczności przy uwzględnieniu kilku scenariuszy dotyczących instalacji PV i dodania baterii magazynującej energię elektryczną, a dotyczących przypadku prosumenta wiejskiego posiadającego mikro-instalcję PV w obliczu wyboru decyzji przejścia na nowy system billingu (NB) lub kontynuację umowy w systemie net-metering (NM) (w nowych warunkach subsydiowania baterii magazynującej). **Metody:** Na podstawie danych wyjściowych sporządzono prognozę cen energii elektrycznej na okres 15. lat i obliczono przyszłe zmiany w kosztach energii elektrycznej dla alterantywnych wariantów, w tym dla gospodarstw domowych nie posiadających instalacji PV. Koszt energii elektrycznej zużytej przez prosumenta obliczono przy użyciu wartości Levelized Cost of Electricity (LCOE) oraz wskaźnika LCOE poszerzonego o konsumpcję (LCOEC) według własnego opracowania. **Wyniki:** W 2037 roku przewiduje się średnią cenę energii elektrycznej na poziomie 2,33 zł/kWh (prawie trzykrotnie wyższą niż w 2022 roku). Podobny wzrost wskazują prognozy w przypadku cen energii elektrycznej wynikającej z taryfy G12 dla gospodarstw domowych. Elastyczność prosumenta w samo-konsumpcji wygenerowanej energii elektrycznej determinuje korzyści wynikające z magazynowania energii elektrycznej, jednakże decydująca jest wysokość dofinansowania do inwestycji PV. Bez wsparcia finansowego wariant rozliczania mikroinstalacji PV z magazynem w systemie net-billingu (NB) nie miałby niższego wskaźnika LCOEC w porównaniu z wariantem net-billlingu (NB) bez magazynu. **Wnioski:** System rozliczeń w formule net-billingu (NB) jest droższy niż wcześniejszy systemu net-meteringu (NM) chociaż posiadanie mikroinstalacji PV wciąż skutkuje mniejszymi rachunkami za energię elektryczną w porównaniu do gospodarstw domowych nie posiadających takiego wyposażenia. Inwestowanie w mikro-instalcje PV będzie kontynuowane przez gospodarstwa domowe, lecz w tempie wolniejszym niż w ostatnich latach.

Słowa kluczowe: prosument, mikroinstalacja PV, system net-billing i net-metering, opłacalność produkcji energii elektrycznej