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DEMAND SIDE RESPOND IN THE CONTEXT OF RENEWABLE ENERGY PROSUMERS

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Purpose: The aim of this paper is to show the problem of adaptation of Demand Side Respond programs to the new market of renewable energy prosumers and to indicate the possibilities and proposals for these adaptations taking into account the current legislation and available solutions such as energy consumption monitoring, energy storage and control of energy consumption with Smart Home solutions.
Design/methodology/approach: The aim of the paper was achieved by analyzing the literature on Demand Side Respond, analyzing the current legislation and analyzing the specifics of prosumer behavior.
Findings: As a result of the analysis, problems related to the adaptation of Demand Side Respond programs for prosumers of energy from renewable sources (especially from PV installations) were indicated and possible solutions were proposed.
Research limitations/implications: Future research will address the development of a set of recommendations for prosumers to optimize their behavior and ultimately contribute to the proper management of energy from PV installations.
Originality/value: The article presents an important issue in the growing renewable energy market resulting from the new prosumer billing system that came into effect on April 1, 2022.

Keywords: Demand Side Respond, prosumer, renewable energy market, prosumer behavior optimization.

Category of the paper: Research paper.

1. Introduction

The demand for electricity in the world is constantly growing. The economic development visible in most countries of the world, including Poland, requires continuous expansion of generating capacity. At the same time, a number of actions resulting from EU regulations, including in particular the RED II Directive (Directive of the European Parliament and of the

Council (EU) 2018/2001 on the promotion of the use of energy from renewable sources) and the EMD Directive (Directive of the European Parliament and of the Council (EU) 2019/944 of June 5, 2019 on common rules for the internal market in electricity) affect the development of renewable energy sources. At the beginning of 2022, the installed capacity of energy from renewable sources in Poland has already reached 17GW, or nearly 30 percent of the total installed capacity. Distributed energy plays and will play an increasingly important role in the country's power system. Renewable energy generation is playing an increasingly important role in the power system due to efforts to reduce dependence on imported fossil fuels as well as to reduce greenhouse gas emissions (Qadrdan et al., 2017). It is important to note that renewable energy production is dependent on weather conditions and therefore does not provide a constant generation capacity. The electricity demand of consumers is also not constant, but varies according to the season, days of the week and hours of the day, etc. The overlap between the variability of consumer demand and the variability of renewable generation further increases the imbalance in the power system.

Differences in supply and demand for electricity result in changes of prices on the energy market. Prices of the electricity available on the Polish Power Exchange are determined separately for each hour. Market mechanisms, based on the forecasted demand-supply relation, decide about the energy price for the current and the next day. The ratio of hourly prices during the day varies from several dozen to several hundred percentage points.

Traditionally, energy demand-side management programs are primarily for industrial customers and involve reducing energy demand during peak hours. Renewable energy prosumers are typically residential customers. This raises the issue of optimizing energy use in this case. The answer to balancing electricity supply and demand as indicated by Antonopoulos et al., (2020), may be provided by Demand Side Respond (DSR). The DSR service is part of a broader Demand Side Management (DSM) program, the role of which is to control demand for power and electricity in such a way as to minimize the costs of developing and operating the power system. Most of the actions are targeted at inducing consumers to rationalize their energy consumption. The effect of these actions is usually the release of peak capacity in the system and avoidance of investment on the part of the generation system and transmission infrastructure.

It should be noted, however, that currently little use is made of the capacity of small distributed consumers to perform DSR and DSM tasks (Cardoso et al., 2020; Marwan et al., 2014; Palensky et al., 2011). The activities of energy companies in this regard are not very lively. This does not mean, however, that small consumers have no technical possibilities and economic potential for such activities. A particularly interesting market segment will be customers with their own renewable sources of electricity generation, i.e., prosumers.

On April 1, 2022, Poland saw a new prosumer billing system come into force, which is completely different from the previous one. The new net-billing system is based on settlements based on the value of energy injected into the grid by the prosumer and not on the quantity of energy injected as before. As of July 1, 2024, the price of energy introduced to the grid by prosumers will be determined for individual hours. This means introducing a wide range of individual consumers to participate in the energy market, giving them the opportunity to take advantage of the benefits of the energy transformation by managing their energy consumption, which will enable them to save money and contribute to an overall reduction in energy consumption. At the same time, it will become necessary to utilize innovative technologies both in the area of energy intensity reduction, energy storage and proper management of owned energy. This paper attempts to outline the issue of optimizing the electricity use of prosumers participating in Demand Side Respond programs.

2. Demand Side Respond

Demand Side Response (DSR) is the service of reducing or shifting the demand for electricity by the end customer in response to changes in electricity prices or at the direction of the transmission system operator. In general, DSR programs can be divided into two categories: price-based and incentive-based programs. The first type includes time-of-use, critical peak price, and real-time price (O'Connell et al., 2014). The second type targets encouraging consumers to reduce their electricity consumption, for example through interruptible tariffs and direct load control (Palensky et al., 2011). Importantly, all these programs can contribute to maintaining stability in the National Power System in case of a difficult balancing situation, especially during peak electricity demand hours. In Poland, the transmission grid operator has so far launched DSR programs for industrial customers. The operator sends a notification and the customer reduces its consumption for a certain period of time and receives remuneration for this operation. The customers participating in the DSR programs can apply one or several mechanisms:

- Temporary limiting of energy consumption.
- Shifting power consumption to other times.
- Switching on the in-house power supply.
- Accumulating energy in or using storage capacity.

The mass installation of smart meters allows looking for opportunities to implement DSR service also for distributed, small-scale electricity consumers. In practice, however, this is extremely difficult to achieve for individual electricity consumers. Simulations by Bućko and Stahl (2020) show a relatively small decrease in peak load despite a noticeable reduction in overall energy demand for the group of consumers in question.

The reason for this is the need for daily use of energy-consuming appliances during the morning and afternoon/evening peak hours such as kettle, electric plate or water heater. This leaves appliances that can be used at other times such as air conditioners, televisions, computers and routers. However, the power consumption of these appliances is generally not significant and, moreover, requires residents to be consistent in shifting their usage hours. In practice, a change of consumption profile requires a change of customer habits which is extremely difficult to achieve, especially for large populations.

One of the more effective methods of engaging consumers in DSR programs is the use of dynamic tariffs. A dynamic price contract is a contract for the sale of electricity that reflects current energy price fluctuations in the markets. However, without appropriate support from innovative technologies, customers would have to continuously control the operation of its receivers and manually adjust their operation to current energy prices. Technological support for the consumer enabling proper use of dynamic tariffs to reduce the energy bill should become one of the key tasks in the era of soaring energy prices.

DSR programs based on dynamic tariffs will be increasingly considered as a way to reduce energy costs, especially for consumers with their own renewable energy sources (RES), i.e., prosumers. New legal regulations require the use of dynamic tariffs in the process of accounting for energy surpluses introduced to the grid from own RES installations.

3. Prosumers

A prosumer is a specific market actor who is engaged in production for personal use (Rupnik, 2010). Prosumption can also include the production of exchangeable goods and services (Toffler, 2006). In the case of the energy sector, with the development of electricity metering technology and Smart Grid technology, a consumer has emerged who is beginning to have an impact on the operation of the energy market. This new consumer called prosumer through actions and reactions to increase its personal benefits or group benefits starts to be an important player in the energy market (Bremdal, 2011). As reported by Heinisch et al., (2019), two factors have been identified to influence the rapid growth of prosumers in the energy market. One factor is economic aspects, such as the increase in retail electricity prices and the reduced prices of PV installations. The second factor is behavioral aspects such as environmental awareness and the desire for greater sufficiency. These factors have influenced the development of the photovoltaic sector also in Poland. The increase in electricity prices and subsidy mechanisms for own generation sources led a significant part of the population to install photovoltaic panels connected to the general power grid. Throughout 2021, 396,514 new photovoltaic installations with a total capacity of 3,774.71 MW were built. The total number of photovoltaic installations is approximately 850,000 units.

The main purpose of the state's promotion of installing its own individual generation sources was to relieve the strain on the country's electricity system by self-consuming its own consumer-generated energy. However, it should be noted that the energy consumption and generation profiles of photovoltaic panels do not match, as shown in Figure 1. A typical generation profile on a sunny day has a peak in its output during the midday hours. This is due to the most common southern orientation of PV panels. In contrast, peak residential power consumption occurs during the morning and afternoon/evening hours.

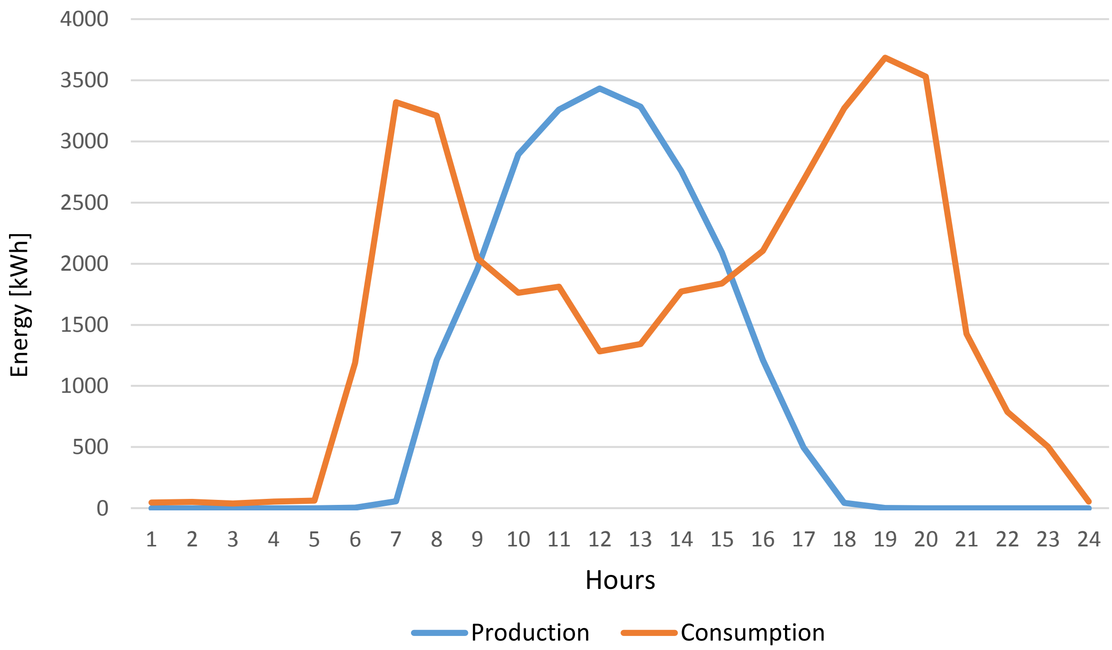

Figure 1. Daily amount of energy generated from the photovoltaic installation and its consumption for the household. Source: own study.

For the typical case of a photovoltaic installation, the problem arises of excess energy during the midday hours. The excess energy from the installation is returned to the grid and can be used by other energy consumers. According to the current provisions of the RES Act applicable to prosumers who concluded an agreement with a seller before April 1, 2022, energy injected into the grid can be returned to the prosumer by the seller at no charge, up to 70 or 80 percent of the energy injected into the grid. This means that the prosumer can treat the grid as an energy storage facility, incurring costs of 20 or 30 percent of the energy it has injected. The prosumer only has to pay for the missing energy from the grid in accordance with the applicable tariff. A slightly oversized photovoltaic installation enables the prosumer to cover its energy requirements in full, eliminating the need to pay any usage charges. However, this is at the expense of the seller, who must pay fees associated with the distribution of energy supplied to the customer. A typical energy input and energy return to the grid per year for a photovoltaic network is shown in Figure 2. As can be seen, the energy input to the grid is much higher than in the months from spring to autumn, which are characterized by higher insolation.

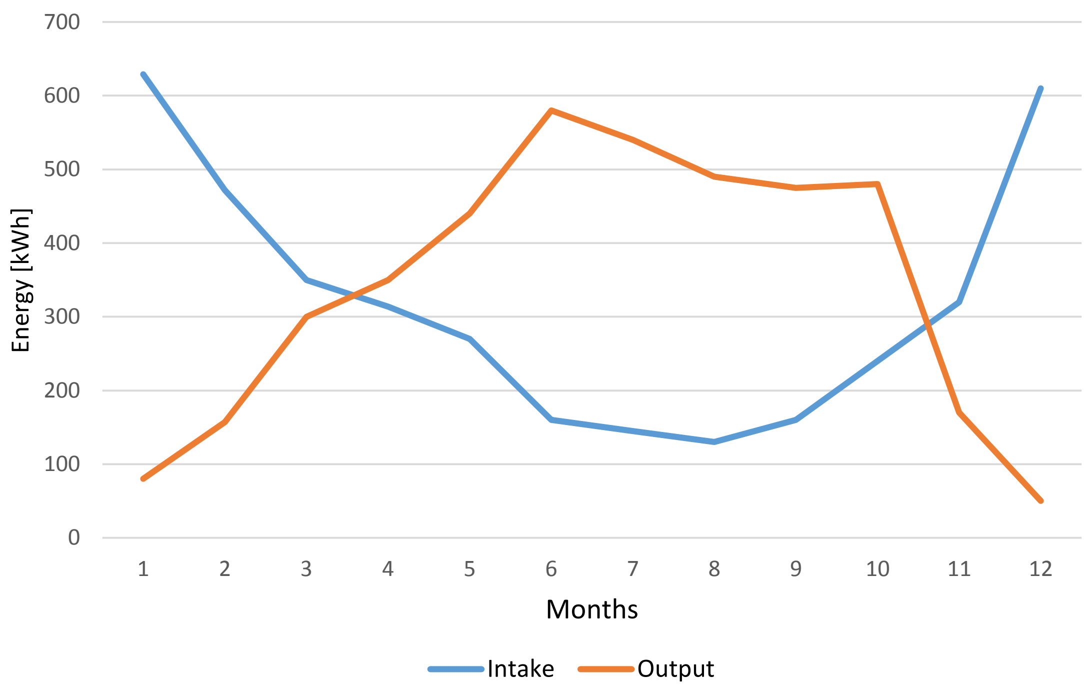

Figure 2. Annual intake and output energy to the grid for the household. Source: own study.

Summarizing the legal *status quo*, prosumers have not been motivated in any way to adjust their consumption to current market signals. Relatively low charges for treating the grid as an energy storage facility do not encourage prosumers to increase self-consumption so that the grid can actually feel the reduction in energy demand especially during peak hours.

The amendment to the RES Act is intended to reverse this unfavorable trend and encourage prosumers to manage the energy they produce much more rationally. The change involves the introduction of a net-billing system consisting in the sale of energy surpluses to the seller. The purchase of energy needed by the prosumer will take place in accordance with market rules applicable to energy consumers, including distribution fees. This is a major difference for the prosumer, as the prosumer receives the equivalent of the energy itself for introducing the energy into the grid, while the consumption of the energy is charged with distribution fees in addition to the purchase. This change has very serious consequences, because investment in one's own photovoltaic system may prove to be not beneficial.

The amended Renewable Energy Sources Act should change the way we use our own energy. As of July 1, 2024, the value of energy injected into the grid will be settled in hourly or 15-minute price gradations. This means that the value of energy sold will be affected by two variables: the quantity and the price of energy in a given hour. Introducing dynamic energy prices means introducing market signals that can be used for energy balance management. Variable prices with skillful control of energy input and output to the grid can to some extent compensate for the need to pay distribution fees. Selling surplus energy at high-price hours and buying it at low prices should become an alternative for prosumers, thanks to which the investment in the generating installation should pay for itself within a few years.

However, the profitability of photovoltaic installations based on new legal regulations requires additional actions, without which it will be difficult to achieve proper management of energy resources and thus profitability of one's own photovoltaic installation.

4. DSR programs for prosumers

In the current legal situation, DSR programs are of particular importance; their introduction may improve the situation of prosumers of photovoltaic energy. It should be noted, however, that such programs make sense when energy consumers are able to recognize their characteristics of energy input and output to the grid. Without this basic knowledge, signal response actions will be chaotic and consequently lead to higher energy usage costs (Heinisch et al., 2019).

This paper proposes Demand Side Response, price-based as well as incentive-based programs to monitor energy consumption, energy storage and control energy consumption using Smart Home solutions.

4.1. Energy consumption monitoring

For an energy consumer, control of energy consumption requires periodic checking of the meter. Then, based on the difference in readings, the consumption for the period is calculated, and knowing the price of the energy makes it easy to calculate the value of the energy consumed. For a prosumer, the situation is much more complicated because the meter shows two values, i.e., energy input and output, and it is very difficult to calculate the amount of energy consumed. This situation raises a fundamental problem related to the need to control energy management, which can be solved by smart metering. Directive 2019/944 on common rules for the internal market in electricity defines "smart metering" as an electronic system by means of which the amount of electricity injected into the grid or the consumption of electricity can be measured, obtaining more information than for a conventional meter, and transmitting and receiving data for information, monitoring and control objectives, using electronic communications. AMI (Advanced Metering Infrastructure) is such a smart metering system. In Poland, classical energy meters are gradually being replaced by AMI meters. These meters have two very important features: they can record the energy consumption for short intervals, e.g., 15 minutes or one hour, and they continuously transmit the current readings to the relevant distributor via a communication module. Some distributors provide their customers with an application through which they can continuously monitor their consumption, but unfortunately not the energy charges. The lack of such functionality results from the principle of "unbundling" of energy distribution and sale, which means that the distributor cannot be informed about the energy price for the customer.

Alternative solutions for AMI are meter overlays or energy monitors installed in the input circuits of the electrical system. The advantages of monitors are unquestionable because in addition to checking the consistency of energy consumption readings by the distributor's meter and energy monitor, it is possible to use much more advanced features. Standard energy monitor collects much more information and higher resolution, e.g., one minute. The data from the monitors are collected in the computing cloud and the results can be observed using specialized applications. It is important that the applications provided with the energy monitors allow for an understanding of how energy is used in the household. Limiting the application to a set of collected data in numerical form or even a graph is clearly insufficient. Analyzing this data sometimes requires specialized knowledge of energy.

One of the important functions of the energy monitoring system is disaggregation of energy consumption for individual energy consumers. Performing disaggregation requires the use of mathematical methods, such as Hidden Markov Models. Knowing the contribution of individual appliances as a function of time and power consumed can definitely help the user make energy management decisions. An example application that facilitates disaggregation of energy consumption data of individual devices in a household is shown in Figure 3.

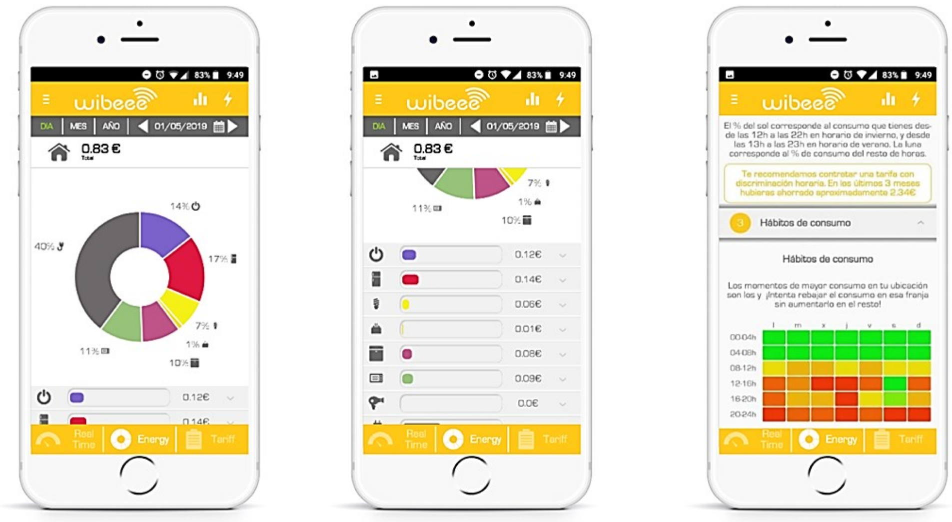

Figure 3. Wibeee application with data disaggregation function.

The analysis of the detailed consumption data and its correlation with energy knowledge, both technical and price knowledge, can lead to the creation of a system of individual recommendations for the customer. An example of such a system is Bidgely's individual customer recommendation module, which is shown in Figure 4.

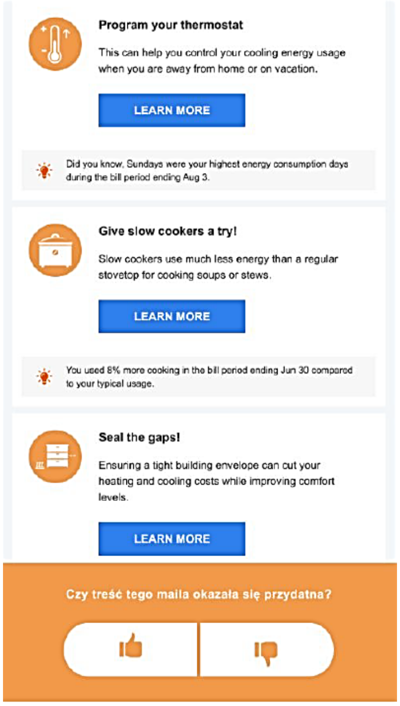

Figure 4. Module of individual recommendations for the customer based on the analysis of consumption and disaggregation of consumption profile.

4.2. Energy storage

Mulder et al. (2013) highlight that residential electricity consumers are likely to become the first available business case involving small-scale electricity storage. Furthermore, the cost of energy storage is expected to continue to decrease, giving prosumers additional opportunities to control the use of the electricity produced and to increase their own consumption of the energy produced by PV panels (Nykvist and Nilsson, 2015).

According to the provisions of the EU Directive (Directive 944/2019), "energy storage" means deferring, in the energy system, the final consumption of electricity from the moment of its generation or converting it into another form of energy that allows it to be stored and then converting such energy back into electricity or using it in the form of another energy carrier. The role of energy storage may be played by electric cars, which are charged from the photovoltaic installation during the hours of maximum energy production. It is also relatively easy and cheap to store energy in the form of heat, which is needed not only during the heating season, but also throughout the year in the form of domestic hot water. An alternative is to install heat pumps powered by photovoltaic installations.

Electricity storage is the most convenient way to store excess production from photovoltaic installations. Collected surpluses can be used at times of increased consumption. The unquestionable advantage of energy storage is the simplicity of increasing self-consumption from your own installation.

The objectives set by the European Union to increase the share of RES in energy production encourage the development and implementation of storage technology. Thus, it is becoming increasingly efficient and accessible to everyone. Energy storage is crucial for improving energy security and for the development of renewable energy. Experts agree that there can be no RES development without energy storage. Therefore, energy storage is another step on the way to transformation of the energy industry.

Despite the undoubted advantages of energy storage, one should pay attention to their limitations and costs. A typical energy storage for PV has a capacity of 3kWh to 10kWh. This means that such a storage can store the surplus from 1-3 days of self-generation. During cloudy and winter periods, the storage will not be able to store enough energy to cover normal demand. The missing energy has to be obtained from the electricity grid. An oversized PV system with energy storage that covers all electricity demand with its own production would certainly not be economically viable.

Smart energy storage control systems can manage the energy from home PV installations. The created consumption and storage scenarios allow for a much more efficient use of energy. The controlling parameters in such solutions can be the operation parameters of the main energy consumers, energy prices in particular time zones and the sunshine forecast required for PV production forecasting.

Figure 5 shows an example comparison of energy prices for the Day-Ahead Market (data from the Power Exchange) with the amount of energy produced during one day – September 14, 2021 (by hour).

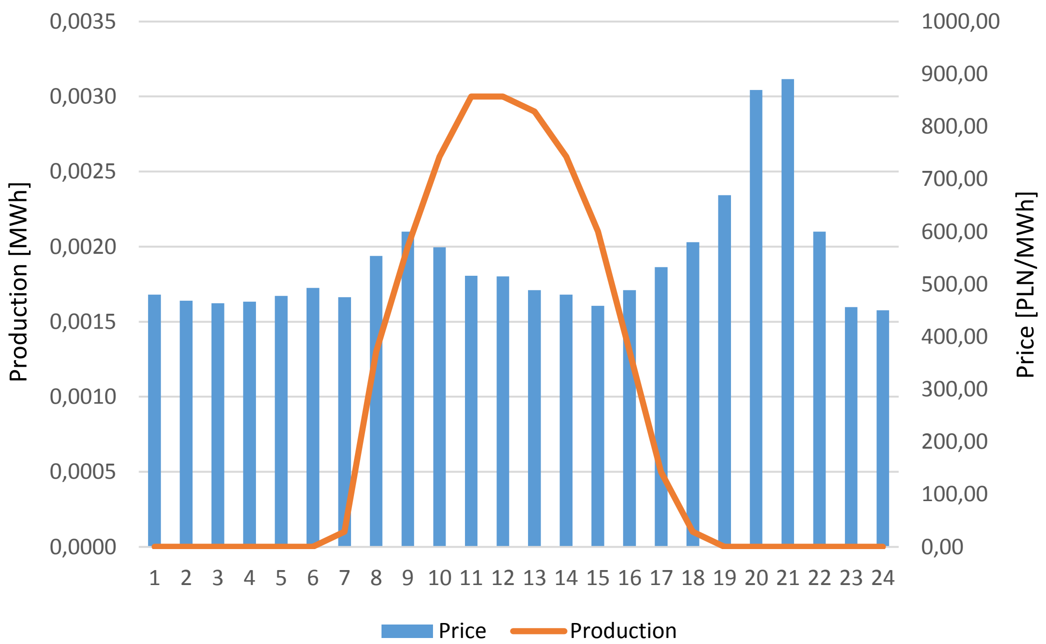

Figure 5. Comparison of Energy Prices for the Day-Ahead Market and Photovoltaic production for an exemplary household. Source: own study.

As can be seen in Figure 5, the energy production of a PV plant is highest in the daytime, between 9 AM and 4 PM, while the energy prices are highest in the evening hours (between 6 PM and 10 PM). In order to reduce the purchase costs, the prosumer should therefore sell the energy, i.e., feed it into the grid during the hours with a high price, and withdraw the energy during the hours with a low price, which can be done with energy storage.

4.3. Controlling energy consumption with Smart Home solutions

Smart Home installations increasing the comfort and safety of life, as well as due to their relatively low cost, are becoming more popular every year especially in the context of the development of energy generation based on renewable sources (Risteska Stojkoska and Trivodaliev, 2016). As emphasized by Beraldi et al. (2020), designing smart homes equipped with energy management systems is even becoming a necessity because in the new energy grid consumers no longer play a passive role but actively contribute to energy production by installing, for example, rooftop solar panels. A Smart Home installation consists of a set of connected intelligent devices (IoT) such as sensors and actuators, usually controlled from a dedicated control panel. Smart Home installation can perform specific tasks such as: switching on and off the lighting according to pre-set scenarios, maintaining room temperature adapted to the time of day and year, creating alarms based on events detected by surveillance cameras, etc.

Often underestimated function of Smart Home is the ability to reduce or change the profile of energy consumption. Apartment lighting divided into sectors and linked to motion sensors can save energy consumption. Even greater savings can be achieved when the home is heated using electric heaters equipped with remote control or connected to smart outlets. Lowering and raising the temperature in the apartment or individual rooms can be implemented on the basis of any scenarios based on, for example, detecting the presence of household members.

Despite the enormous possibilities of controlling energy-consuming devices, typical Smart Home installations very rarely implement scenarios aimed at achieving goals related to energy efficiency or even lowering energy bills. The reason for this state of affairs should be seen in the lack of broader awareness of such opportunities by investors and designers, and more importantly in the lack of motivation. Rising energy prices and the introduction of a DSR-based billing system for prosumers should definitely change this state of affairs.

5. Summary

The problems related to the development of electricity generation from renewable sources, which have been mentioned in the paper, indicate the necessity of applying Demand Side Respond for a new type of producer and consumer, i.e., the prosumer. When adapting DSR programs for prosumers, however, many challenges need to be taken into account, such as:

- Variable electricity production dependent on technical parameters of the installation, time of day, season and weather conditions.
- Variable energy consumption that depends on deterministic factors such as time of year and length of day as well as stochastic elements related to individual customer behavior.
- Variable configuration of energy consumers.
- Variable energy storage capacity, both in the form of energy storage and other forms of storage such as hot water tanks.
- Variable energy prices determined by market conditions.

With so many variables, it is extremely difficult for the prosumer to decide how to manage energy at any given time. With very high price fluctuations such as those currently observed on the Polish Power Exchange, a good strategy may be to feed-in the surplus energy into the grid during the hours with high prices. In a different system, a scenario based on maximizing the use of one's own energy might be more advantageous.

Despite the announced subsidies, the new way of accounting for energy bringing prosumers closer to participating in the energy market may be a barrier to profitability for many potential investors. Without appropriate support systems to manage their own energy, there will be no one willing to invest in building their own RES sources. Therefore, it is necessary to create solutions that will take over the functions of support for energy management by prosumers in the conditions of application of DSR/DSM systems.

Currently, there are many solutions of this type, but they are addressed mainly to industrial consumers and are limited to the implementation of specific scenarios. In this situation, there is a great need expressed by companies installing PV systems to support customers in the efficient use of energy adapted to the changed legal conditions.

In order for prosumers to effectively use their own energy under the conditions of DSR/DSM, it becomes necessary to make available on a mass scale software in the form of mobile applications, web portals or autonomous control applications that, based on the individual configuration of generation, storage, consumption, metering and control systems available at home, would supervise energy management. For example, if the prosumer has a Smart Home installation it is appropriate to enable the transmission of control signals from the control system to the Smart Home control panel. Otherwise, the prosumer should receive personalized messages with recommendations that will improve energy efficiency in their case. A prosumer with energy storage can, for a change, try a form of energy trading based on price volatility. Such operations can be performed within the prosumer's deposit or by reselling energy to an aggregator.

The changes introduced by the amended RES Act in the functioning of prosumers' settlements may slow down the extremely intensive development of own RES installations. On the other hand, the rapid increase in energy prices should encourage consumers to switch to their own energy sources. Therefore, there is an urgent need to support prosumers in order for them to skillfully use the opportunity offered by the transition from a system of fixed tariff prices to dynamic prices. The solution may be programs containing recommendations for prosumers, which will aim to optimize their behavior and, as a result, contribute to the rational use of natural resources and optimization of energy use.

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