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1 Executive Summary

The aim of the deliverable D6.2 is to report the technical analyses regarding the development of community-based energy cluster concepts and flexibility services for the various complexes targeted in the Przywidz municipality. The energy clusters are understood very broadly as a concept requiring an analysis of the possibilities of creating energy communities in Poland by checking their feasibility in various aspects: legal, technical, social and economical. The detailed verification of conditions is done in the use case sites. D6.2 refers to Task 6.3, which is planned till the end of the project, so this deliverable does not cover the whole scope of the work in this task. Especially the part regarding the analysis of the systems used to organise the financial relations between the members of the community (e.g. blockchain technology) will be presented in the next report, as the rules for the community and responsibilities have to be fully established. In the current, dynamically changing, situation in Poland, establishing a community that would be reasonable is a challenge.

Deliverable D6.2 is aimed at presenting the current situation in Poland regarding the status and possibilities to develop more sustainable and climate-change aware rural areas, which would impact decarbonisation and development of renewable energy in Poland. The general economical situation is explained to give the context. The historical situation concerning the development of renewable energy sources, legal aspects and problems connected to them are presented. The deliverable also presents the general idea of energy communities in Europe and the implementation of those ideas in Poland.

The technical analysis part consist of the analysis of combining different users/prosumers to optimise the use of renewable energy sources; the creation of the energy cooperative; the discussion of possible neighbourhood batteries - which is briefly outlined - and, last but not least, the flexibility services, especially demand response services.

The aim of the task is to develop the concept of the energy cluster organisational frame. A group of interested local stakeholders will be identified. The main players of the cluster will be proposed in line with the new energy law in Poland; the coordinator of the energy cluster, the energy operator, the main energy producers and the users will all be identified. In addition, the business model for the energy cluster will be developed. The local electricity grid will be analysed from a technical point of view, taking into account the possibility of the development of a local community-based energy in Przywidz. The influence of at least 20 private and/or municipal micro-RES installations (photovoltaic, heat pumps) and the electric vehicles charging stations on the local low voltage energy grid will be analysed. New flexibility services for network operation will be developed and tested.

2 Introduction

2.1 Summary of the SERENE project

The aim of the SERENE project is to develop and demonstrate sustainable, integrated, cost-effective and customer centric solutions for local communities. The idea is to integrate different energy system carriers and new renewable generation units in the local communities, based on the current social and technical status to meet their energy needs in the coming years.

To make decisions about their participation, the users have to be involved in the changes of the energy system and have to be informed about different technical opportunities and business cases. The SERENE project has three demonstrator sites in Przywidz. Depending on the actual site, the new energy systems involve different storage technologies (battery energy storages, heat storages, water storage-systems), demand response systems to enhance the flexibility of the systems (activating for instance electric vehicle charging stations and heat demand supplies), electric transportation systems such as electrical vehicles or buses, heating system improvements using heat-pumps and integration of new renewable generation sources mainly in form of photovoltaics. The SERENE project will establish demonstrations in local villages in three European countries - Denmark, The Netherlands and Poland. The experiences gained at the demonstration sites will be analysed and evaluated for replicability, firstly in Europe but also worldwide. Technical benchmark models and solutions will be set up together with their business models, and an evaluation will be performed on how different legal aspects from the involved countries will affect the possibility for replication. In addition, the needed user involvement and the user interest to join are evaluated, from the point of view of geographic, social, environmental and economic conditions and characteristics.

2.2 Summary of WP6 – Polish Demonstrator

The Polish demonstrator is located in the Przywidz Municipality in the Pomorskie Voivodenship, located in the north of Poland just south of Gdańsk. The demonstrator consists of 3 use cases, each of them focussing on a different type of facility and on different opportunities. The use cases are presented in the following sections.

The project also considers non-technical innovations such as the concept of energy clusters or energy communities, which is part of ambitious renewable energy policies. The general idea behind such clusters is a social change, in which the local counties and municipalities will involve local citizens and stakeholders in the creation of sustainable ‘energy nests’. The aim of this is to meet and manage the energy demand locally by utilising local energy resources, creating local entrepreneurs and enabling socio-economic-environmental benefits.

The specific objectives are:

- The installation of measurement and instrumentation systems at various consumer and building premises. This allows to conduct data analytics of heat and electricity profiles as well as other relevant parameters for flexibility estimation and upgradation needed for integrated local energy systems;
- The implementation of smart control and operation of integrated solutions of heat pumps and energy storages (battery, heat exchangers) to increase the share of photovoltaic self-

consumption at the energy complexes and buildings involved in the demonstration. The techno-economic impacts on the local electricity grid will also be analysed;

- Demonstration of flow battery storage, public electric vehicles charging stations and vehicle-to-grid (V2G) functionality, at the school facilities, and their smart control with DSM and integrated energy management system that involves HVAC and photovoltaic systems.

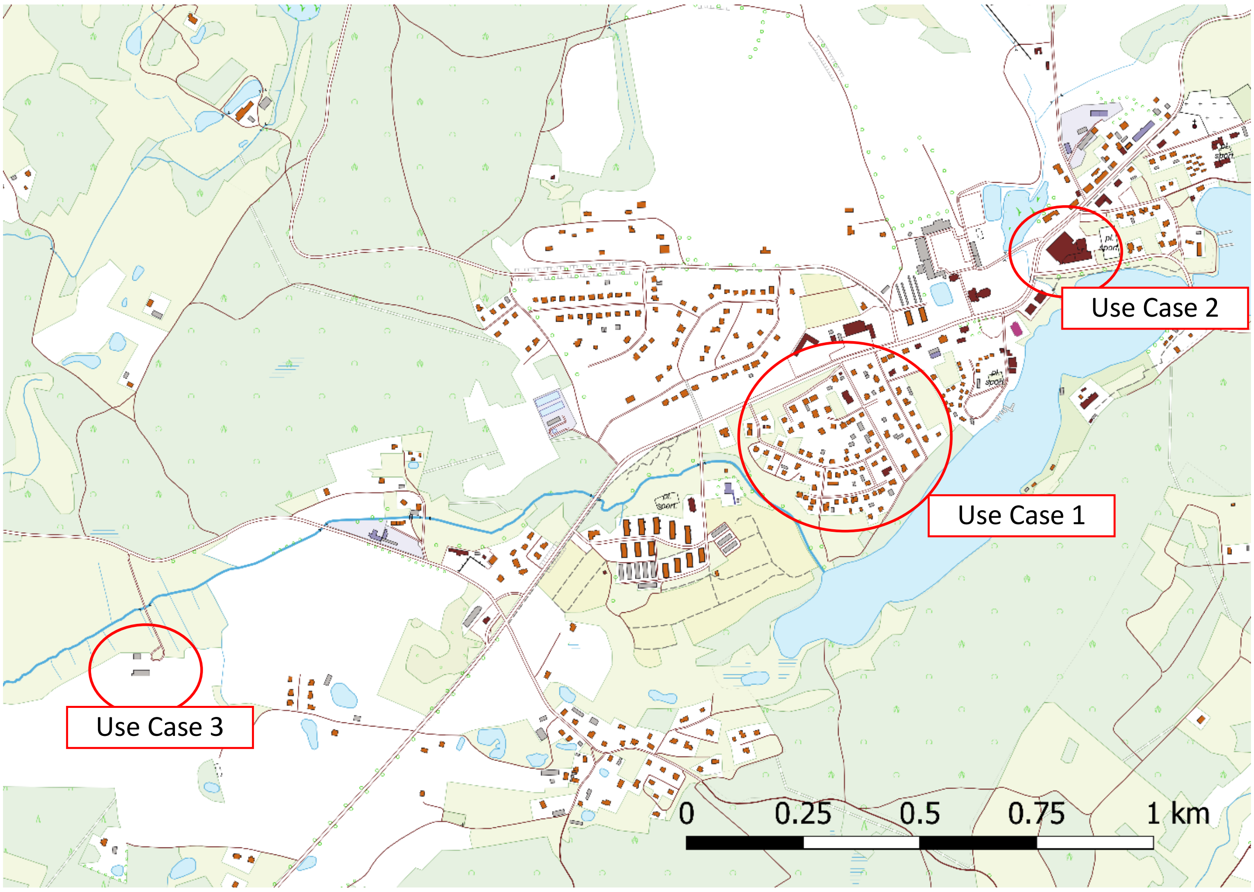


Figure 1 The overview of the Use Case areas.

The local authorities and citizens have already participated in a number of programs to introduce renewable energy sources and modernize existing infrastructure. They also took part in research projects that were aimed at drawing the pathway for the municipality for a more sustainable development. In recent years, these efforts resulted in the installation of around 120 solar collector installations and more than 250 photovoltaic installations in the municipality, and in the installation of 14 heat pumps in 7 municipality buildings for heating and hot water preparation. At present, the vast majority of private homes use coal heating in private boiler rooms, some use gas or biomass; around 1230 houses have solar collectors to heat water. As a result of all of the modernizations, the municipality now emits 3.5 t less CO_2 daily, which sums up to 1300 t CO_2 less emission annually. This is mainly due to 1.6 MW photovoltaic installations on 260 private houses, 10 administration buildings and on the roof of the parking near the municipal office. On the municipal office itself the photovoltaic installation has 20 kWp, while the biggest installation is near the sewage treatment plant of 49.96 kWp. On private buildings, modules of 2.5 to 7.5 kWp were installed, the majority of citizens have a photovoltaic installation of more than 6 kWp.

2.3 Use Case 1 - The district of Przywidz village

The first Use Case is focussed on the most populated area in the centre of Przywidz. The overall aim of this Use Case is twofold: to improve the operation of the photovoltaic (PV) installations in the area (by reducing the curtailment of production) by testing a mobile energy storage unit and to gather data regarding usage and peoples' behaviour to begin work towards energy communities or energy clusters in the area. The area contains buildings that are connected to a single secondary substation. One hundred metering points are directly connected to the substation, but some of them are considered to be outside of the area of interest (e.g one of the objects is the camping which is connected to two different substations). As a result, 96 energy connection points are considered, most of which are houses. The non-residential ones are the local clinic, a pumping station, a kindergarten and few technical buildings. The area has a number of photovoltaic installations (32 in total), which are affecting the voltage quality in the area. The citizens have reported problems with their photovoltaic production during summer, but due to lack of the proper monitoring it was not clear what the exact nature of the problems is. The work in this Use Case includes measuring the electrical situation in the area, testing if a mobile energy storage can improve the quality of electricity (esp. if it can reduce curtailments and, in a way, increase self-consumption), and installing the measuring infrastructure in the kindergarten and at selected households. The map showing the location is presented in Figure 2. The mobile battery is a 25 KW, 64 kWh all-in-one energy storage system that can be reconnected between different points in the grid. The mobile energy storage is planned to be connected to the following locations:

1. Public kindergarten – photovoltaic and heat pump energy balancing will be demonstrated with the aim to minimize energy flow (maximize self-consumption) and energy cost. Demonstration of intentional islanding operation is planned.
2. Pump station – since it is placed near a transformer substation, it is intended to influence power quality at low voltage terminals. ESS integrated with substation measurements shall provide energy balancing, reactive power compensation and voltage support features.

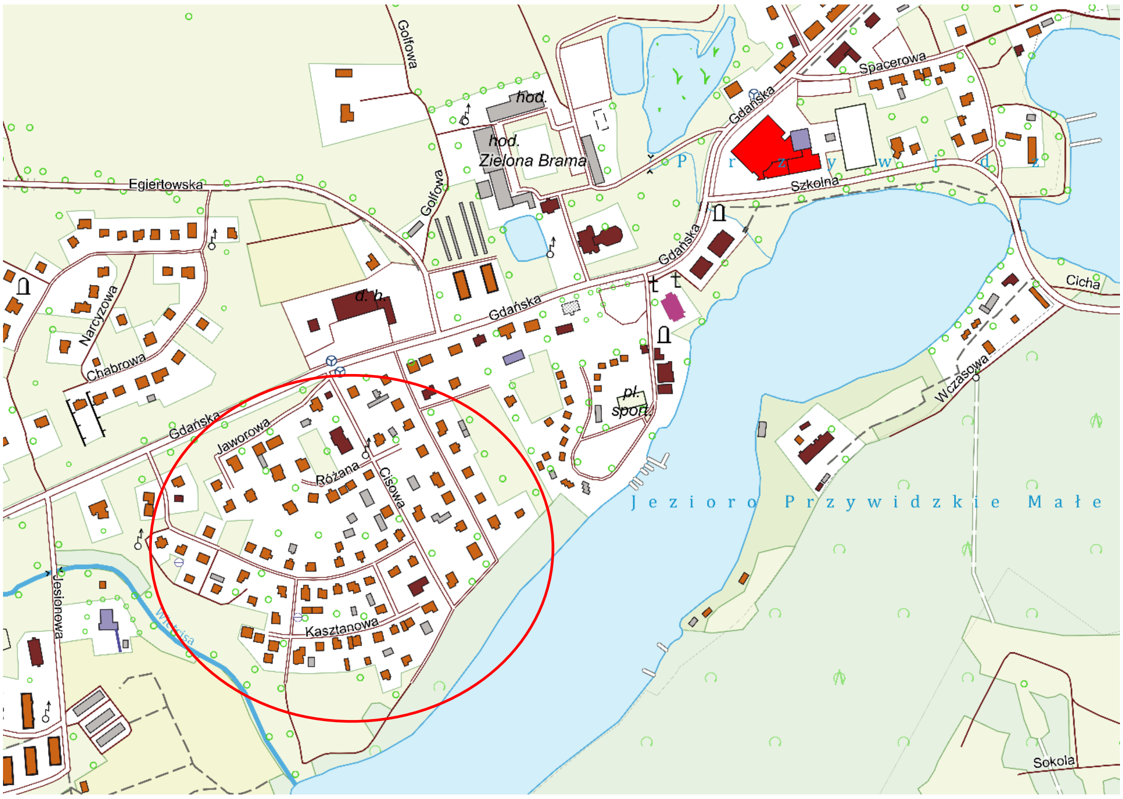


Figure 2 District of Przywidz that is part of the Use Case 1 (red circle) and Arena Przywidz with the school (in red) that is Use Case 2.

2.4 Use Case 2 School and sport centre

Arena Przywidz (marked in red on Figure 2, photographs on Figure 3) and the primary school (Szkoła podstawowa im. Unii Europejskiej, also marked in red on Figure 2) are located at the heart of Przywidz, very near to the municipality office building. The Arena and the school are connected with a junction, but at this point they still have two separate electrical connections and two separate heating systems. The power of photovoltaics installed on the sport hall and on the school are respectively 39.99 kWp and 26.04 kWp. The aim of the Use Case is to implement an energy measuring system that would allow to increase the self-consumption from the photovoltaic installation in Arena Przywidz and demonstrate the role of an energy storage unit in such a building complex.

Figure 3 Photographs of Arena Przywidz.

Arena Przywidz will be equipped with an energy storage unit and electric vehicles (EV) charging points. The energy storage will be a Vanadium Redox Flow Battery (VRFB), which is presently not very popular, even though it has several interesting advantages. The energy density is smaller than that of Li-Ion energy storage but it has a large number of cycles (20,000+) and can use the full range of capacity (the charge range is from 0 to 100% of the initial capacity). The plan is to install a 20kW, 96kWh system in a container next to the building. In the final stage of the demonstration, the mobile energy storage will be combined with this VRFB to form a hybrid energy storage system.

One electric vehicles DC charger of more than 20kW has been installed and is frequently used to charge the electrical public transport bus. The installation of two additional chargers, one which offers V2G and another one which at this point is still undefined, is also planned. At the beginning, the chargers will not be open for public use as there are legal issues with trading or giving energy from installations belonging to the municipality, those limitations will be lifted in time. All those devices will be connected by the Energy Management System (EMS) that will manage the energy storage and the charging of the cars. The EMS will provide energy balancing with the aim to minimize energy cost.

Presently, the heating system in the school and the Arena is based on LPG boilers. In the SERENE project, 3 heat pumps (23kW heating power each) were installed in the school (Figure 4).

Figure 4 Heat pumps installed in the school roof.

No changes to the structure of the Arena heating system are planned, but a measuring system will be installed. The installed temporary measuring system provided data about the usage of Arena Przywidz (Figure 5). Based on the data, we can state here that potentially the energy storage system can increase the self-consumption of energy from photovoltaic installation and also reduce usage peaks.

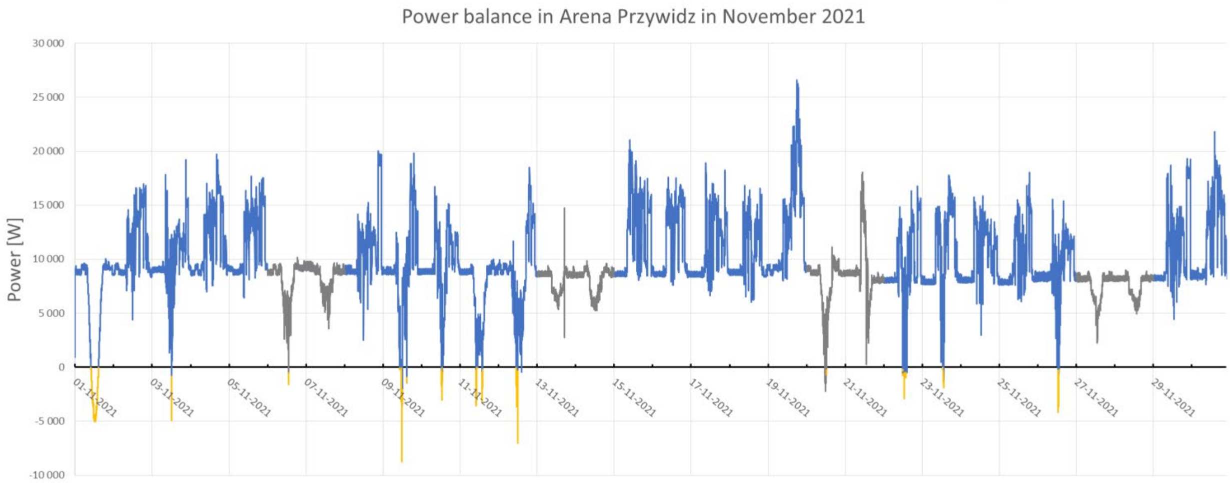


Figure 5 Measurements of the energy balance in Arena Przywidz, example data for November 2021.

From 1st of March 2021, there is an electric bus line to transport citizens and school children around Przywidz. This bus has its bus terminal near Arena Przywidz, where it can charge from the electric vehicles DC charger.

Figure 6 Electric bus that is used regularly on line 868 that drives around Przywidz.

2.5 Use Case 3 – The sewage treatment plant

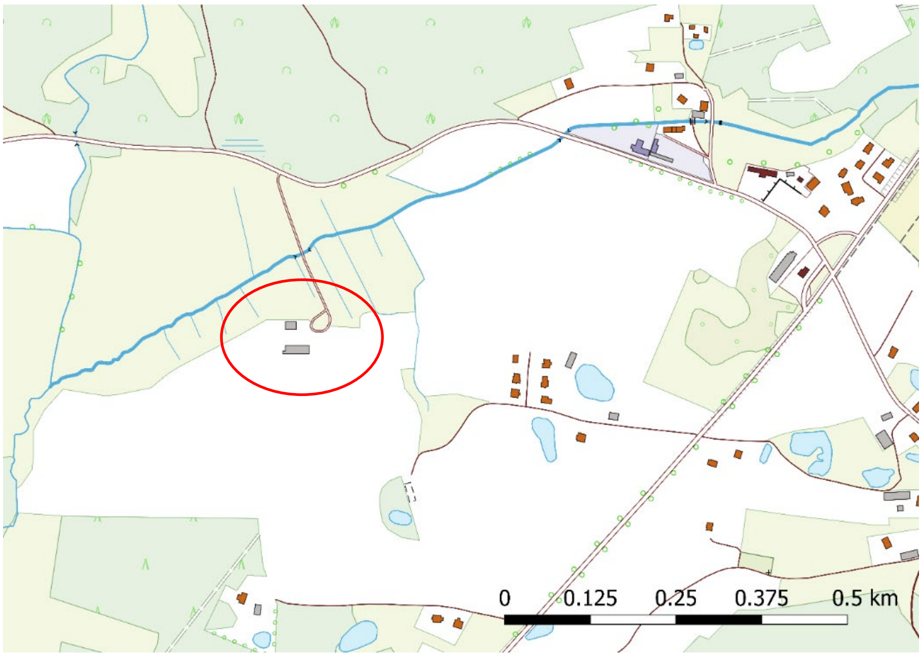


Figure 7 The location of the sewage treatment plant in Przywidz municipality in the village Piekło Dolne.

This Use Case will research and demonstrate the possibilities of using municipality facilities in DSR activities. The sewage treatment plant in Przywidz is a new and modern facility (opened in 2021), shown in Figure 8. It processes more than 95% of the sewage from Przywidz. The treatment plant uses a biological purification process, which takes a long time to react to changes of the process parameters; the optimal settings for daily operations were achieved in February-March 2022.

The Przywidz Municipality supplied the schemas of the wastewater processing plant and the description of the process. Near the sewage treatment plant there is a photovoltaic installation of 49.95 kWp. There is no need to heat or cool down the reservoirs – the treatment process does not require it – but power is needed for operational aspects such as pumping. The buildings use electricity as a heat source. The facility is equipped with a diesel power generator to ensure constant operation of the facility (Figure 9).

Figure 8 Sewage treatment plant in Przywidz.

Figure 9 Power generator in the sewage treatment plant.

3 Description of the socio-economic and environmental situation in Przywidz and region

3.1 General information

Przywidz is a rural municipality in the Pomeranian Voivodeship, in the Gdańsk county. It is located in the Kashubian area in Eastern Pomerania. Figure 10 shows the geographic location of the municipality. The municipality consists of 18 villages: Przywidz – which shares the name with the municipality, Borowina, Częstocin, Huta Dolna, Jodłowno, Kierzkowo, Kozia Góra, Marszewska Góra, Marszewska Kolonia, Michalin, Miłowo, Nowa Wieś Przywidzka, Olszanka, Piekło Górne, Pomlewo, Stara Huta, Sucha Huta, Trzepowo. The total area of the municipality is 12 934 ha (129 km^2), which is around 16.3% of the area of Gdańsk county. Part of the Municipality is the nature protection area NATURA 2000. The region is famous for its beautiful nature and for a number of lakes. The landscape is generally hilly, the height of hills reaches up to 270 m above sea level. The biggest lake in the municipality - Przywidzkie lake - has a length of 4.5 km and an area of 130 ha. Przywidz is a very popular area for holidays in summer (water sports, bicycle trips), but also in winter (skiing possibilities, it has for example two ski-slopes).

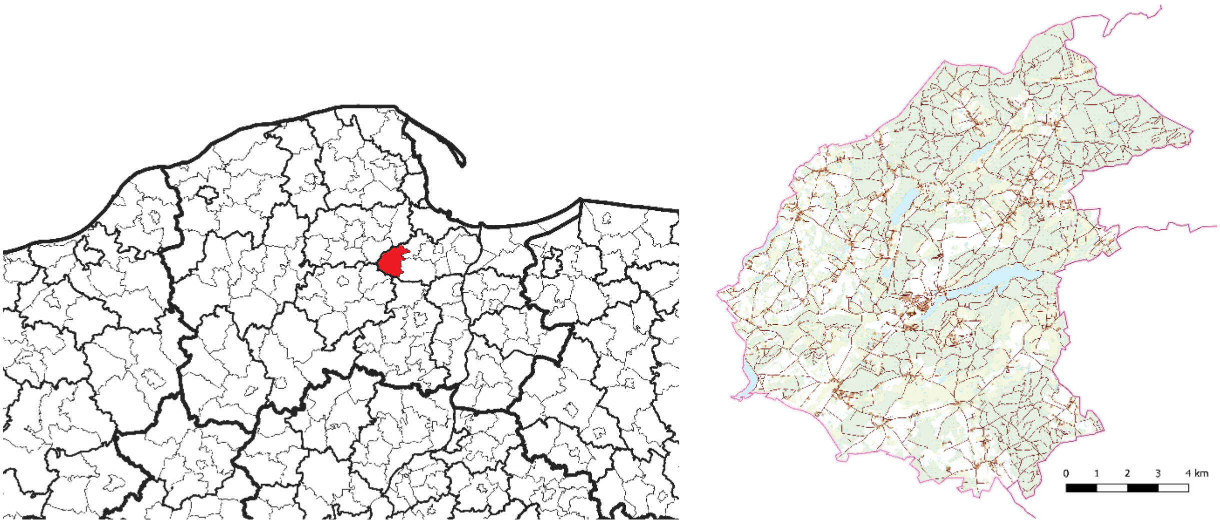


Figure 10 Location of the Przywidz Municipality in Poland.

The surface of the municipality is covered mainly by forest and farmlands, the urbanised areas make up only 3.4% of the total area (Table 1).

Table 1 List of cadastral area of land [ha] in Przywidz Municipality [1].

Land usage	Area [ha]	% of municipality's area
Farmland	6 190	47,9%
Forest	5 682	43,9%
Urbanized area	458	3,5%
Other	322	2,5%
Sum	**12 934**	**100,0%**

3.2 Short history of the municipality

The first mention in the historical sources of *Przywidzka Land* appeared over 700 years ago, around the 14th century. A document from 1294 mentions that the Pomeranian duke Mestwin II granted the properties of Przywidz, Trzepowo and Klonowo to the Cistercian Order of Eldena. This grant was confirmed by king Władysław Łokietek in 1328. Initially, the owners were the bishops of Kuyavia, then the inhabitants of Gdańsk - the Catholic Przywidzki family, and after the Reformation, the Protestant Linde family.

After the Partitions of Poland (1772–1795), the area of Przywidz was within the borders of Prussia. By the end of the 19th century, all the currently existing towns in the municipality are mentioned in the documents. According to sources, Przywidz at that time housed a church and an Evangelical school, a watermill, a steam distillery, a starch factory, a brickyard, and a post station providing passenger and mail connections with Gdańsk and Kościerzyna. In 1920, after the creation of the reborn Poland, Przywidz found itself outside Polish borders, due to its incorporation into the newly created Free City of Gdańsk. At that time, the inhabitants of Gdańsk 'discovered' recreation in the Mariensee – as Przywidz was called at the time. It was then named the 'air resort', or 'Little Sopot'. In 1924, the Senate of the Free City of Gdańsk commissioned the construction of a Polish Youth Hostel in the town.

After World War II, when Gdańsk and its surroundings returned to Poland, Przywidz, thanks to its location by the lake and among the forests, became again a place of weekend rest for the inhabitants of Gdańsk, as well as a destination for summer tourism and employee holidays.

Przywidz is located in the Kashubian region, home to the Kashiubian ethnic group culture, with its own language, literature and cuisine.

3.3 Climate

The climate of Przywidz is influenced by an oceanic climate, but due to its elevated location the snow stays much longer in comparison with areas by the seaside. There is frequent rainfall throughout the year. The average annual temperature is 12°C and the annual rainfall is 316 mm. It is dry for 164 days a year with a humidity of 79% and a UV index of 3. There is a high difference in yearly wind speed. In winter, the wind tends to be stronger with an average slightly exceeding 19 km/h. The most windy month is January where average wind speed is 22 km/h. In summer the average wind speed is 15,7 km/h. The average temperatures are presented in Table 2.

Table 2 Average monthly temperatures for each month of the year in Przywidz.

Month	Average temperature	Avg. highest temperature	Avg. minimal temperature
1	0.1	4.8	-9.0
2	1.1	5.9	-3.9
3	3.0	6.9	-1.8
4	7.0	9.4	5.1
5	11.7	14.8	8.8
6	15.4	17.9	13.5
7	18.2	21.9	15.8
8	18.1	21.1	15.2
9	14.3	16.9	11.9
10	9.4	12.0	6.9
11	4.5	7.3	-0.4
12	1.2	6.2	-4.7

3.4 Demography

In the Przywidz municipality live 5960 inhabitants (data from the census in 2021) (3008 men and 2952 women), which gives the density of 47 people per square km. In total there are 1442 buildings and 1776 flats. The average size of the flat is 123,4 square meters and by average there are 5,1 rooms [2]. The majority of people in Przywidz live in single-family houses, usually those buildings have 2 floors. The distribution of the population can be obtained from GUS [3] in 1 by 1km grid (data from 2011). This data is presented on Figure 11. This data is overlaid with a map of buildings, the colour of which indicates the type of which (residential, commercial, …).

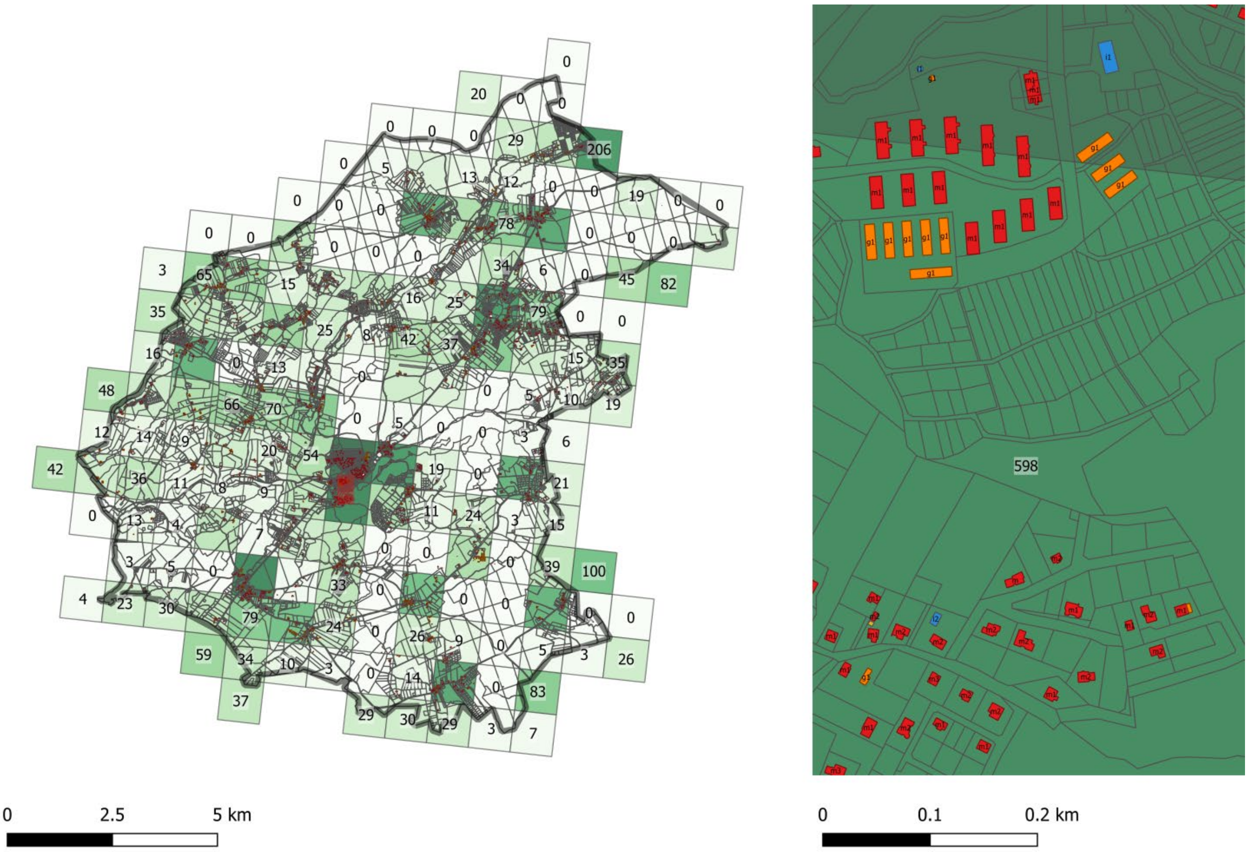


Figure 11 Population distribution in Przywidz Municipality (source: GUS).

Using additional data, for example data regarding land lots it is possible to disaggregate the population over the buildings and areas – Figure 12 also shows the issues with this disaggregation, as buildings do not perfectly match the population grid. The calculations done by Fluid-Flow Machinery Institute were verified by data from the municipality so the population distribution for the area is to some extent known. Data obtained via the municipality are unfortunately not open to public.

Figure 12 Population disaggregation on buildings using public GUS data.

The age structure in Przywidz is similar to the overall population structure in Poland. The age structure is presented in Figure 13 and the working age structure in Figure 14 [4].

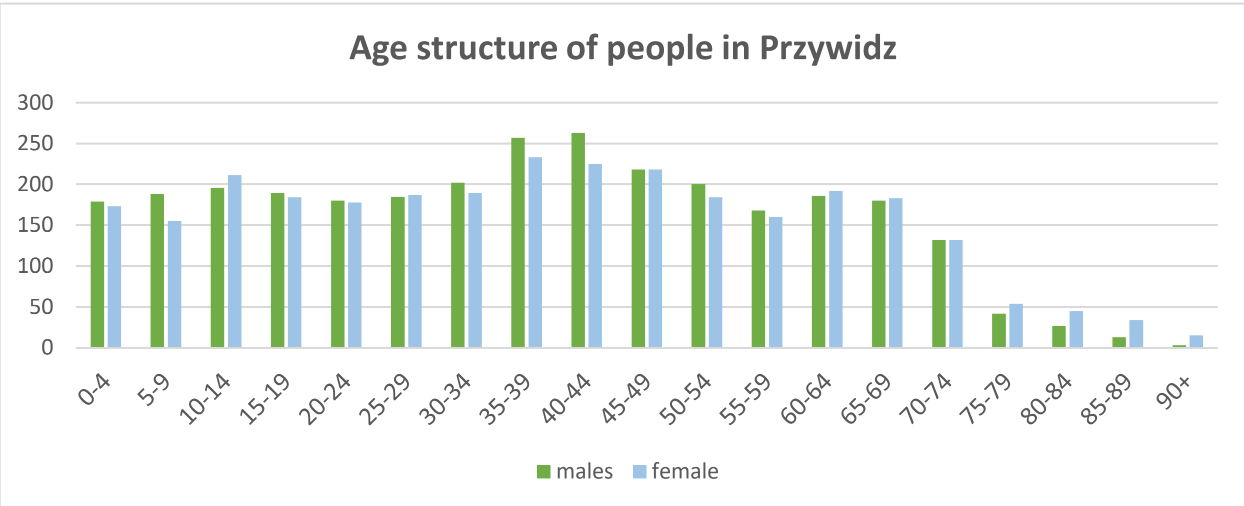


Figure 13 Population age structure in Przywidz.

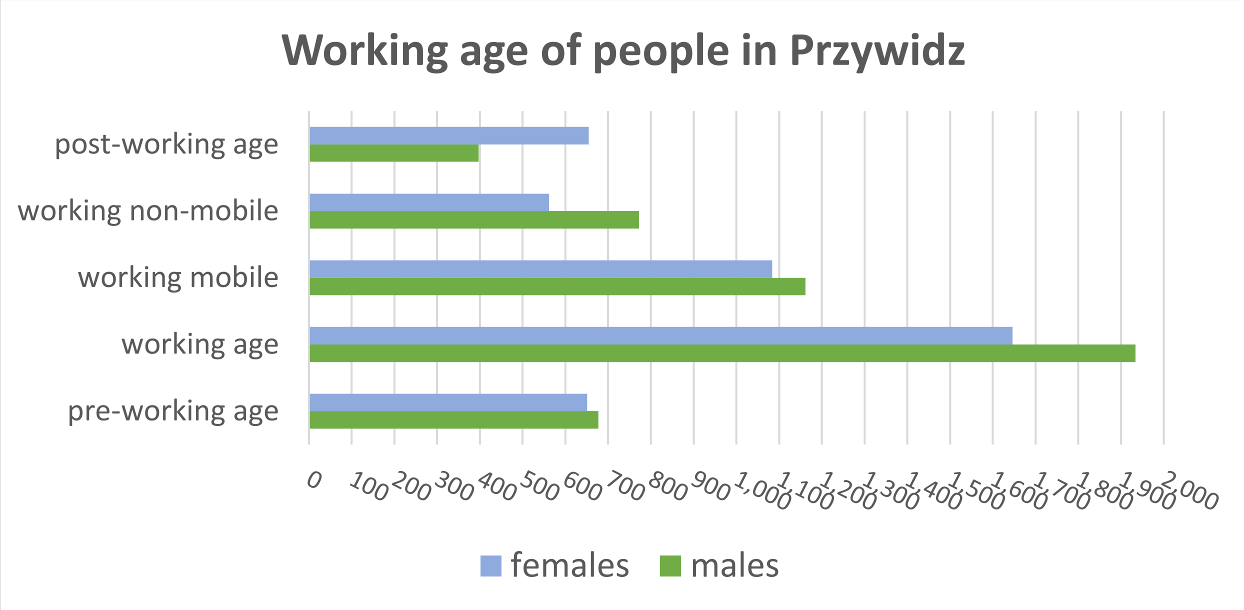


Figure 14 Working age structure in Przywidz.

3.5 *Economic situation of population*

The pre-pandemic situation in the region was relatively good and stable, the salaries were steadily growing. The pandemic brought one strict lockdown starting from March 2020, which was gradually released by March 2021, when the large scale vaccination started. There were around 2 months of very strict limitations for travelling and business, which worsened the economic situation of companies, especially those connected to tourism and hospitality industry. The companies were just slightly aided by the temporary subsidies from government. Almost all limitations were removed by March 2022 and by then there were high hopes for a return to economic growth. Unfortunately, in February 2022 the war in Ukraine started. This had enormous impact on the Polish economy due to a number of factors: the immigration of Ukrainian population, the fuel crisis, restrictions in importing Russian hard coal and the gas supply crisis. All of that lead to high inflation, raising interest rates and an increase of the prices of fuels. The situation is turbulent and not predictable, the inflation in Poland reached 17,5% in November 2022 [5]. The salaries were growing but with lower dynamics, which made the people relatively poorer; unfortunately the comprehensive analysis of the situation and the change in levels of poverty (also in energy context) are not yet fully known. Below, the data describing the situation of Polish citizens are presented: some data are gathered and published on the voivodship levels, some are regional.

In 2021, the census took place which gives relatively recent data regarding the situation of Polish households. We have gathered data from Region Atlas [6] – the tool for presenting regional data from Central Statistical Office (GUS); the values are in PLN, the exchange rate is 1 EUR = 4.67 PLN. Some of financial data are only available on region level (Przywidz is in Gdański region), other data are only provided on voivodship level (Przywidz is in Pomorskie voivodship).

The values for changes in average salary for the whole country are presented in Table 3, the changes in minimal salary is presented in Table 4.

Table 3 Average salary for Poland. 1 EUR = 4,67

Period	Value [EUR]	Value [PLN]
IV quarter 2022	1432.10	6687.92*
III quarter 2022	1387.72	6480.67
II quarter 2022	1318.25	6156.25
I quarter 2022	1335.16	6235.22
IV quarter 2021	1283.74	5995.09
III quarter 2021	1211.41	5657.30
II quarter 2021	1178.70	5504.52
I quarter 2021	1216.61	5681.56
IV quarter 2020	1168.73	5457.98
III quarter 2020	1106.84	5168.93
II quarter 2020	1075.91	5024.48
I quarter 2020	1141.64	5331.47
IV quarter 2019	1113.19	5198.58
***prognosis**		

Table 4 Minimal salary for Poland. 1 EUR = 4,67

Valid from	Minimal salary netto [EUR]	Minimal salary netto [PLN]	Minimal wage per hour [EUR]	Minimal wage per hour [PLN]
01.01.2022	644.54	3010	4.22	19.70
01.01.2021	599.57	2800	3.92	18.30
01.01.2020	556.75	2600	3.64	17.00
01.01.2019	481.80	2250	3.15	14.70
01.01.2018	449.68	2100	2.93	13.70

Figure 15 shows the gross domestic Product per capita (GDP). The Gdański region has a relatively low GDP (in the lower group in the voivodship), but it should be remarked that the cities of Gdańsk, Gdynia and Sopot are not in Gdański region but in the small neighbouring Trójmiejski region - which has the highest GDP per capita in the voivodship. There are no big economic cities in the Gdański region area, while the region is home to several national parks and protected reserves.

The average monthly gross wages and salary - shown on Figure 16 at voivodship level - are average for the country. This data covers the wages and salaries of entities of the national economy with 10 or more employed persons and budgetary sphere units, regardless of the number of employed persons. Given the spatial resolution, the value for the area of Przywidz can be assumed to be slightly below the indicated value, based on the distribution of the GDP in the voivodship (Figure 15).

Figure 17 presents the average monthly available income per household per capita, also at voivodship level. The sum of the current incomes of the household from all sources reduced by advances towards personal income tax paid by the employer on behalf of the tax-payer, by taxes paid from income from property, by taxes paid by self-employed persons, including freelance professionals and persons using private farm in agriculture and by social security and health insurance premiums. The available income covers both income in cash and in kind, including natural consumption as well as goods and services received free of charge. This map shows that the Gdański region is rather in the lower half in Poland. The discrepancy with Figure 16 can be explained by e.g. a larger non-active population (for example due to bigger households).

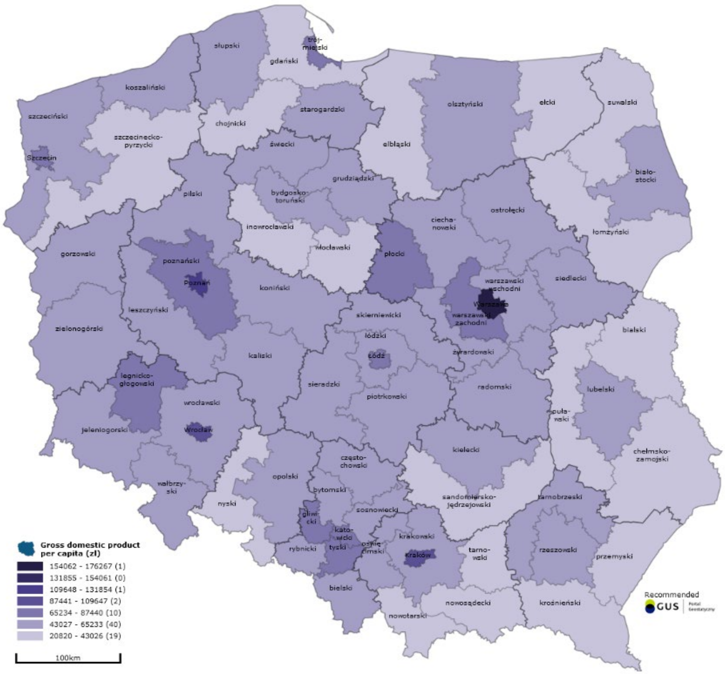


Figure 15 Gross domestic product per capita, in PLN, values calculated according to the European System of Accounts ESA 2010, the resolution is on microregions.

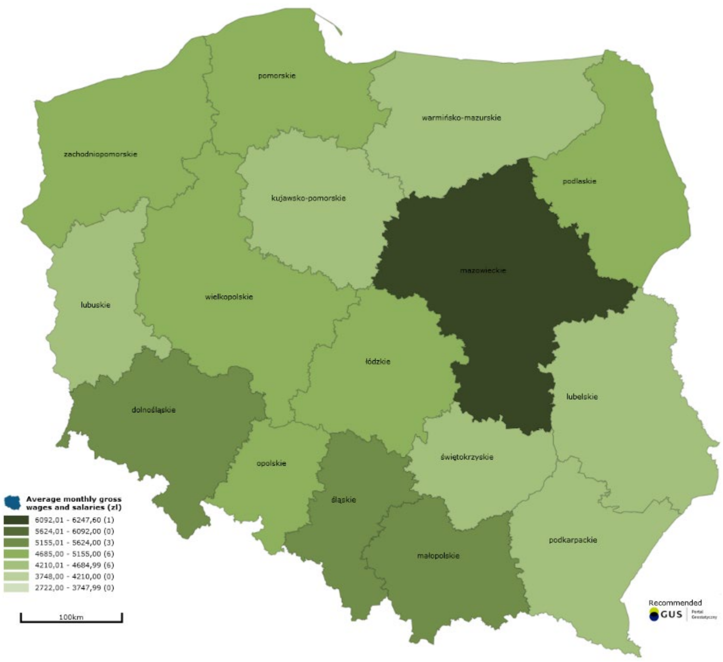


Figure 16 Average monthly gross wages and salaries in PLN, data on wages are given in gross terms, i.e. including deductions for income tax of natural persons and compulsory social security contributions (retirement pay, disability pension, and sick benefit) paid by insured employees.

Figure 17 Average monthly available income in the household per capita in PLN. The value is the sum of current incomes of households from all sources reduced by advances towards personal income tax deducted by the employer on behalf of the tax-payer, by taxes paid from income from property, by taxes paid by self-employed persons, and by social security and health insurance premiums.

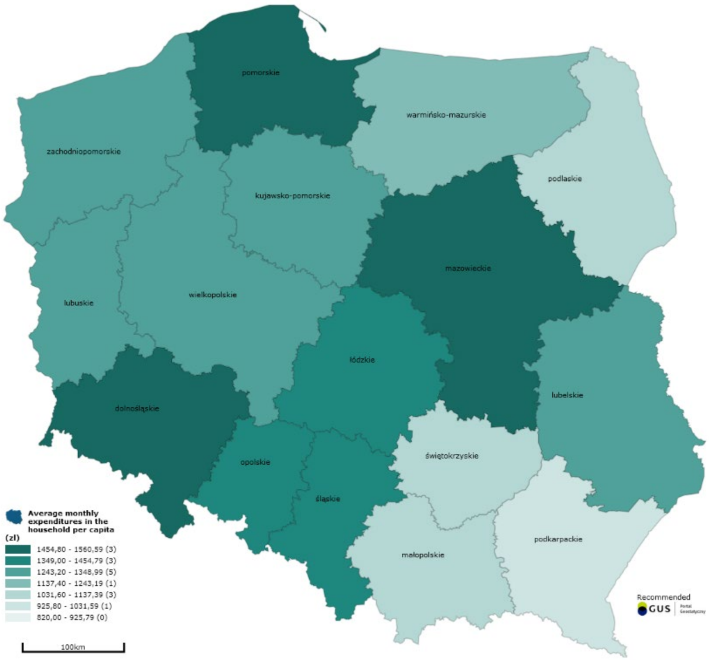


Figure 18 Average monthly expenditures in the household per capita.

Table 5 provides a summary of the average amount and value spent by households on energy. This is divided between the cost of energy carriers used for domestic purpose and the cost of energy carriers used for transport. Average monthly expenditures in the household per capita is presented in Figure 18. While energy related, due to its relevance as a necessary expenditure for households, its magnitude is of importance from a socio-economic point of view. Combined with Figure 17, we can see that in Pomorskie, the average energy cost is between 2 and 3 times the average monthly income per household per capita.

Table 5 Energy usage and cost per household, the aggregated value of all energy carriers for domestic use and fuel for transport [2].

	Yearly average of use in households		Country usage for households	
	amount	value	amount	value
	GJ	PLN	TJ	MLN PLN
Energy carriers (no hot water)	81	4 267	1 085 702	57 318
Motor fuels	46	6 440	408 598	57 256

As it results from the analyzes and presented statistics, Przywidz is not a typical rural community dealing only with agriculture. It is an area whose inhabitants mostly work outside agricultural production and commute to work in larger agglomerations. Therefore, electricity from photovoltaic installations operating in private homes is often not consumed locally, except for weekends, but is rather sent to the grid, which may generate its overload. At the same time, however, there are several large facilities in the municipality, such as a school, a sports hall or an office whose working hours and electricity demand may coincide with this production. This fact is a potential starting point for the creation of a local energy market within the energy community from the technical point of view.

In addition, taking into account the statistics on local expenditure on energy (heating and transport) in relation to the statistical income of local residents, it can be seen that there is a huge need to reduce these costs in order to avoid energy poverty. One way can be local cooperation within the energy community to reduce these expenses for the poorest and potentially use cheap renewable energy produced locally or potentially from shared installations (possibly co-financed by the municipality or external funds). Therefore, there is a need to analyze new business models.

Looking at the local expenditure on fuels in transport, there is a potential for savings by using electric vehicles for which the energy could be produced from local renewable sources. Locally available electric vehicle charging stations and electric vehicles demonstrated in SERENE will be the first steps in the development of this field in the municipality. Consequently, Przywidz as a village is the focal point of the community with a dozen or so small villages in the area - the use of an electric bus in Use Case 2 for the daily transport of children to school is an excellent demonstration of this technology.

As can be seen from the description of the commune, its environmental values are in large part the driving force behind the developing local tourism. In order to preserve this natural character, and at the same time develop the community, it is necessary to act in a very sustainable manner and with respect for all social groups. Meetings with residents proposed under SERENE concerning various aspects of the community's energy policy, new organizational possibilities in the form of, for example, energy cooperatives or new flexibility services in cooperation with the local DSO are the first steps to creating a local community that has a real impact on the sustainable development of its surroundings.

3.6 Energy needs and usage – heating.

The main statistical office publishes heat usage data on voivodship level – the last report was made in 2020, where the data for different target groups were presented, those groups are: Industry and construction, Transport and Small consumers sector [7]. The small consumers sector is further divided into heat consumption in households, agriculture and other. The heat consumption division for the Pomorskie voivodship is presented in Figure 19, the values exclude consumption in units from the sections 'Mining and quarrying', 'Electricity, gas, steam and air conditioning supply' and 'Water supply; sewerage, waste management and remediation activities'.

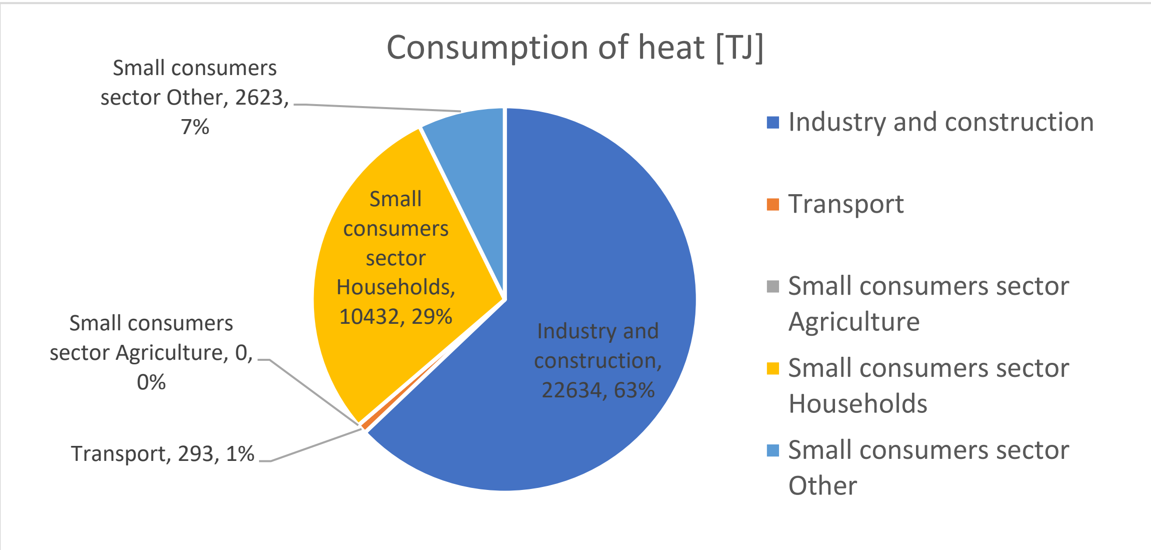


Figure 19 Consumption of heat in Pomorskie voivodenship [7].

Regarding the use of energy carriers for heating, data are only available at the country level. The analysis is done every 3 years by GUS and the Ministry of Energy; data from 2019 are presented in Table 6 [8].

Table 6 Usage of Energy carriers for the heating purpose in Poland, year 2019.

Energy carriers	Usage of energy carriers for heating purpose						
	for heating (no agricultural activity)	for heating of rooms - primary source	for heating rooms - additional source frequently used	for heating rooms - additional source rarely used	for heating domestic water	for cooking	for agriculture production
	in %						
Electricity	81.91	2.90	1.05	1.37	24.47	76.43	6.98
District heating	40.04	39.65	0.09	0.08	X	X	-
Hot water from district heating	32.23	X	X	X	32.23	X	-
Natural gas	55.89	14.67	0.51	0.39	25.95	51.69	0.04
Liqiud gas (propan-butan)	33.31	0.34	0.18	0.09	1.34	33.16	0.37
Fuel oil	0.49	0.42	X	0.11	0.27	X	X
Hard coal	35.54	31.97	2.74	0.43	21.17	1.57	0.34
Lignite	0.37	0.28	0.09	X	0.12	0.00	-
Coke	0.55	0.49	0.09	0.02	0.20	X	-
Wood	26.64	8.24	14.19	3.12	12.18	1.99	0.32
Other biomass	1.10	0.78	0.33	0.11	0.75	0.09	X
Solar energy	2.01	0.01	0.03	0.08	1.97	X	0.02
Heat pump	0.85	0.25	0.13	0.01	0.81	X	-

At country level, district heating prevails – this is connected to the fact that a large amount of the population lives in cities and most of the Polish cities have a well developed district heating network. The second and third most popular energy carriers are hard coal and natural gas. In Przywidz, there is no district heating and no natural gas supply network, but the LPG gas is very popular (it is also used to heat the Arena Przywidz).

The hard coal was, for very long time, one of the cheaper ways to heat for households, but also the most polluting. For the last 20 years, cities are making huge efforts to convince citizens to get rid of their coal furnaces and to change to other types of heating (mainly natural gas). In rural areas such activities were much less present and introduced later. A number of subsidies for modernization of heating or for thermomodernization are now available for rural areas – coming from national and local programs. The stability of the prices of coal was one of the main factors that made people reluctant to change the heat source. The war in Ukraine changed the situation – Poland was importing huge amounts of coal from Russia and when the sanctions were in place the prices of coal went up to 3000 PLN per ton in summer 2022 (the price in 2021 was below 1000 PLN per ton).

The prices of natural gas were very stable for years, Poland for years was trying to get independence from Gazprom, which included building a LNG terminal. Unfortunately, the war and decision not to buy natural gas from Russia has shaken the market and the prices to a large extent. The prices for the households were stable in 2022, as they were frozen by the government; unfortunately for companies the prices were changing reaching 0.650 PLN/kWh. In 2023 the Polish government froze the prices for households at the level of 0.2001 PLN/kWh. The change of the prices for natural gas and hard coal are presented in Table 7.

Table 7 Price dynamics of the most popular energy carriers.

Year	2015	2016	2017	2018	2019	2020	2021	2022
Hard coal [PLN/t] [2]	789.33	780.38	823.59	887.30	885.40	887.95	996.60	2329.03
Natural gas [PLN/kWh] [9]	0.1336	0.1209	0.1155	0.1167	0.1266	0.1168	0.1211	0.2001

The high costs of heating and water preparation can be reduced by using heat pumps powered by locally produced electricity from renewable sources. Potential cooperation within the local energy community and the sharing of electricity combined with the additional use of electricity and heat storage facilities should give an opportunity to further reduce these costs and provide access to cheaper energy, in particular to the poorest who cannot afford an individual source of renewable energy.

3.6.1 CEEB database

Up to now, the information about the heat sources in Polish households were estimated based on the statistical office surveys, but they were averaged and not fully representing the situation in municipalities. On the 1st of July 2021 the CEEB (Centralna Ewidencja Emisyjności Budynków, eng. Central register of emissivity of buildings) database was opened – it is a database gathering data about the heat sources and every building in Poland should be in this database. Its goal is to improve air quality by eliminating the main cause of pollution - emissions of substances that cause smog. In addition, it is a valuable tool that supports the replacement of old heating boilers and helps in the application for financial subsidies for it.

Submission of the declaration is mandatory. Every owner or manager of a building is required to submit a declaration with information on the heat sources installed and fuels used for combustion up to 1 MW. Information on heat sources already in operation had to be submitted from July 1, 2021 to June 30, 2022. For newly established and commissioned sources, the owner has 14 days to report it from the date of activation. There are financial penalties for not declaring or exceeding the allowed notification deadlines. Declarations can be completed electronically, by submitting them in person to the city/municipality office according to the location of the building, or by sending them by post.

The declaration is separated into two categories. Type A should be filled out for residential buildings including single-family houses, multi-family buildings and collective residence buildings. Type B is for non-residential buildings such as office, commercial buildings or public facilities. When completing the declaration, it is necessary to select the type of owned source or sources. In each of them the information whether it is in use must be marked; if it is in use then it needs to be specified for what purpose - heating, domestic water heating or both at the same time. The order of entered sources is does not imply a priority or importance.

In the declaration the following sources can be selected:

- district heating network,
- solid fuel boiler with manual fuel feed,
- solid fuel boiler with automatic fuel feed,
- fireplace
- tiled stove for solid fuel,
- kitchen stove,
- gas boiler
- oil boiler,
- heat pump,
- electric heating/boiler,
- solar thermal collectors.

For solid fuel boilers, the class and number of boilers installed should be specified, as well as the type of solid fuels used in them.

As it turned out, after the initial analysis of the database content, there were a lot of inaccuracies or mistakes in the collected data. These consisted of incorrect data filled by owners e.g. marking the use of the district heating network in a location where it does not exist. Sometimes owners did not specify the way in which the source is being used. The database is still being developed and one can expect changes and corrections in next years. The year 2023 should be the first where the data declared will be verified with the reality by controllers.

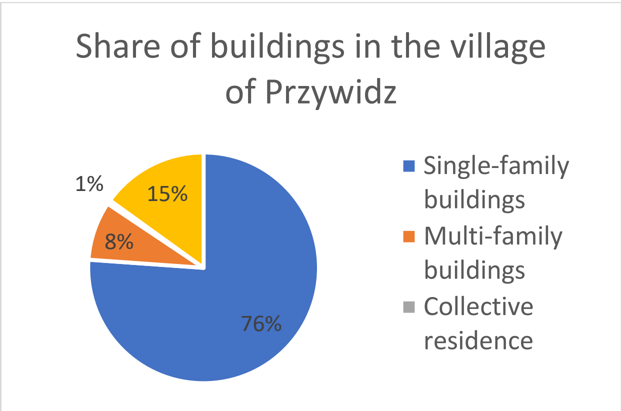


Figure 20 Share of buildings in the village of Przywidz according to the CEEB declarations.

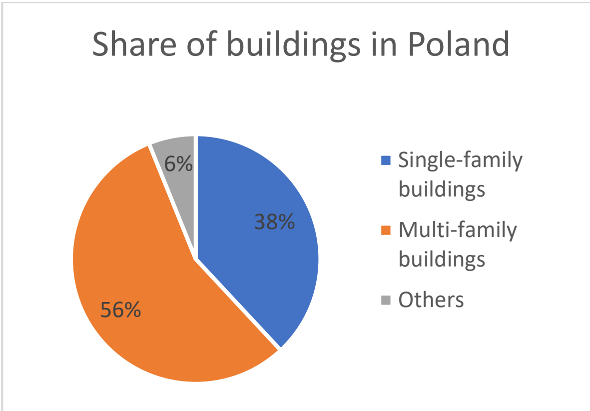


Figure 21 Share of buildings in Poland from central statistical office.

Comparing the data for Poland provided by the Central Statistical Office (2018) and the obtained percentage of each type of building in Przywidz, one can observe that there is a much higher share of single-family residential buildings than multi-family buildings. In the village of Przywidz, multi-family residential and collective residence buildings have a much smaller percentage than in the country.

There were 1440 declarations analyzed, in which a total of 2118 heat sources were registered: between one to four sources per building were declared. The largest amount of declared sources were fireplaces and solid fuel boilers, both with manual and automatic feeders. Highly significant are also electric heating, heat pumps and solar panels. Tiled stoves, gas (LPG) boilers, kitchen stoves, oil boilers and the district heating network figure marginally as heat sources. Even though Przywidz does not have a district heating network as such, it appears in the CEEB database as there are a few blocks of flats that share a single heat source: in the declarations this was considered as a heat network (the shared heat source is coal based, but a change to heatpumps is in progress). A similar relationship can be observed in the share of sources identified as operating. The smallest share of sources in use to all installed sources is found for tiled and kitchen stoves and fireplaces. This is related to the fact that these are currently less frequently used sources due to the relatively high amount of pollution they produce. Further details on the installed heat sources in Przywidz are presented in Figure 22 - Figure 26.

Table 7. The types of the heat sources declared in CEEB for Przywidz.

	present	in use
Gas boiler	60	59
Solid fuel boiler – automatic sub.	392	374
Solid fuel boiler – manual sub.	416	408
Oil boiler	38	35
Solar collectors	91	86
Fireplace	491	418
District heating network	19	18
Electric heating	372	343
Tiled stove	69	56
Heat pump	116	108
Kitchen stove	54	45
Total	2118	1950

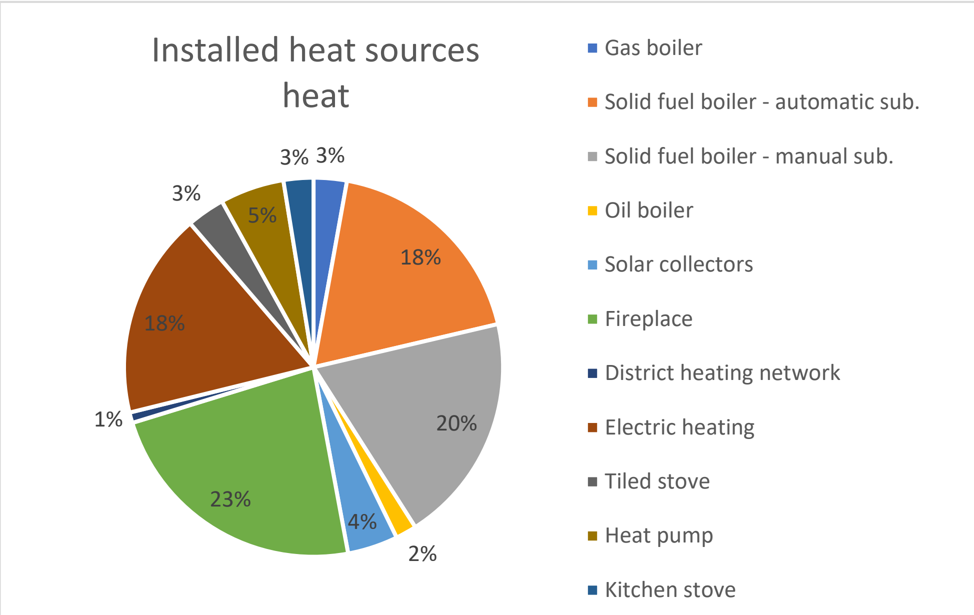


Figure 22 The percentages of different type of heat sources in Przywidz, source: CEEB.

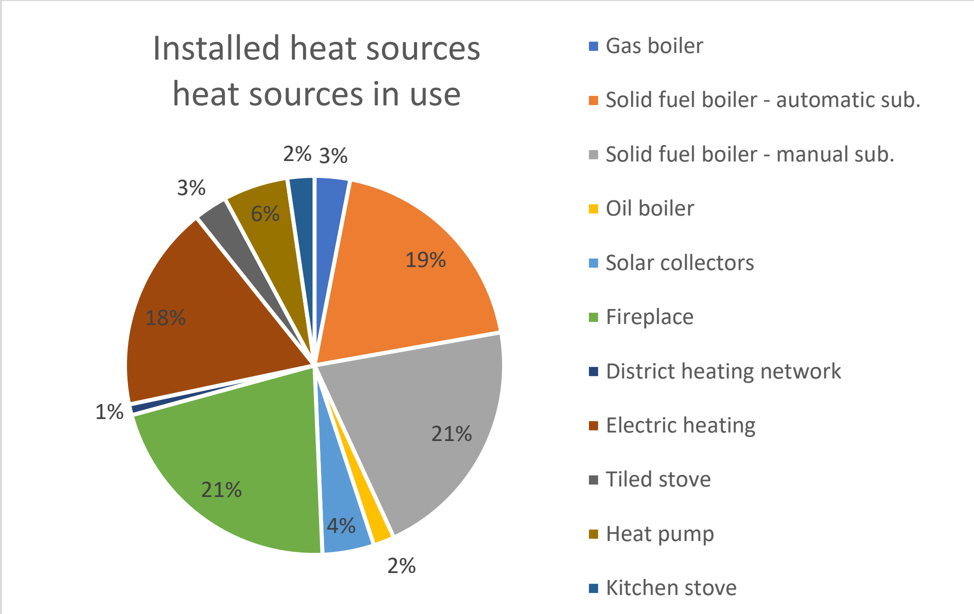


Figure 23 The heat sources in use in Przywidz, source: CEEB.

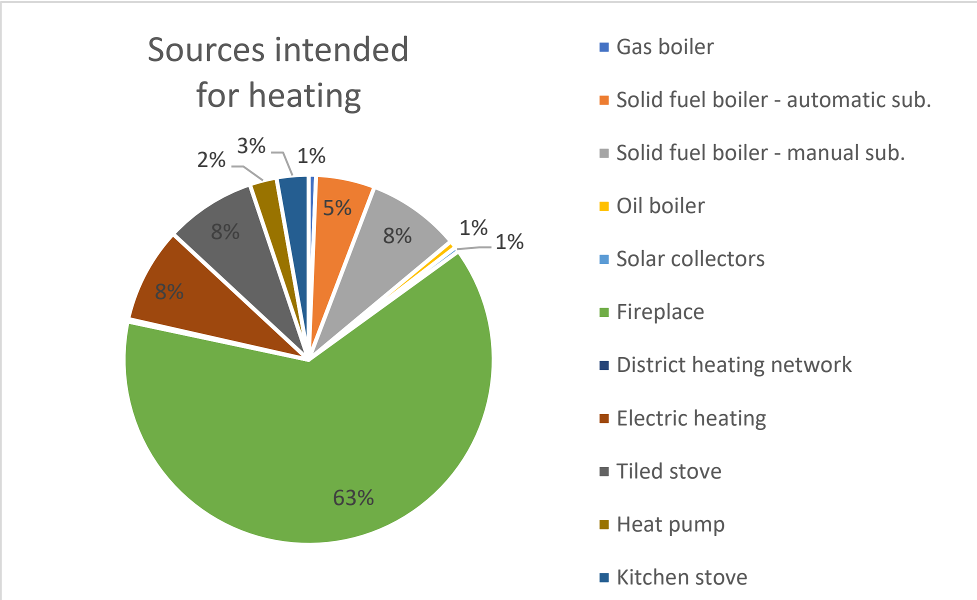


Figure 24 Heat sources used only for heating.

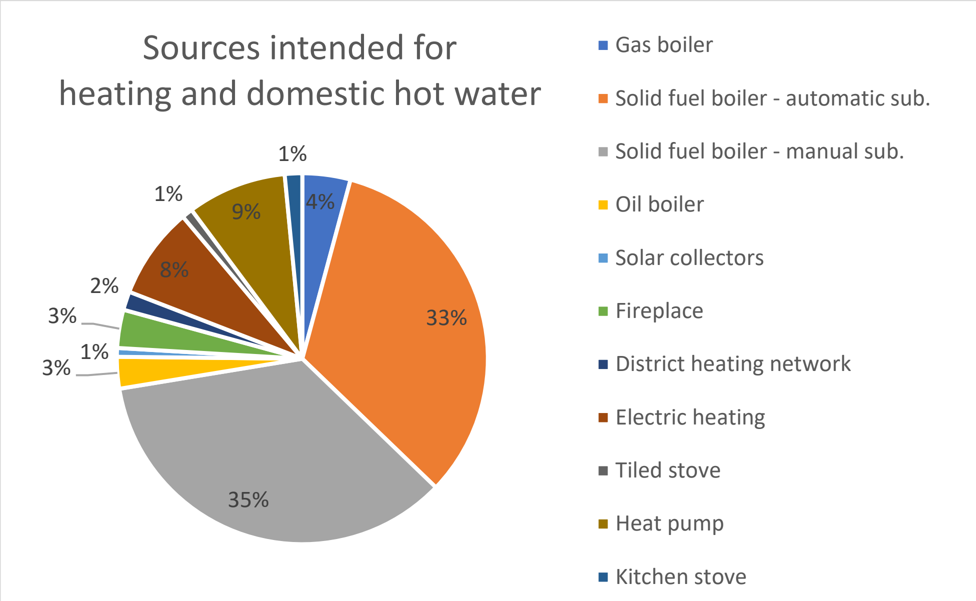


Figure 25 Heat sources used for both: heating and domestic hot water.

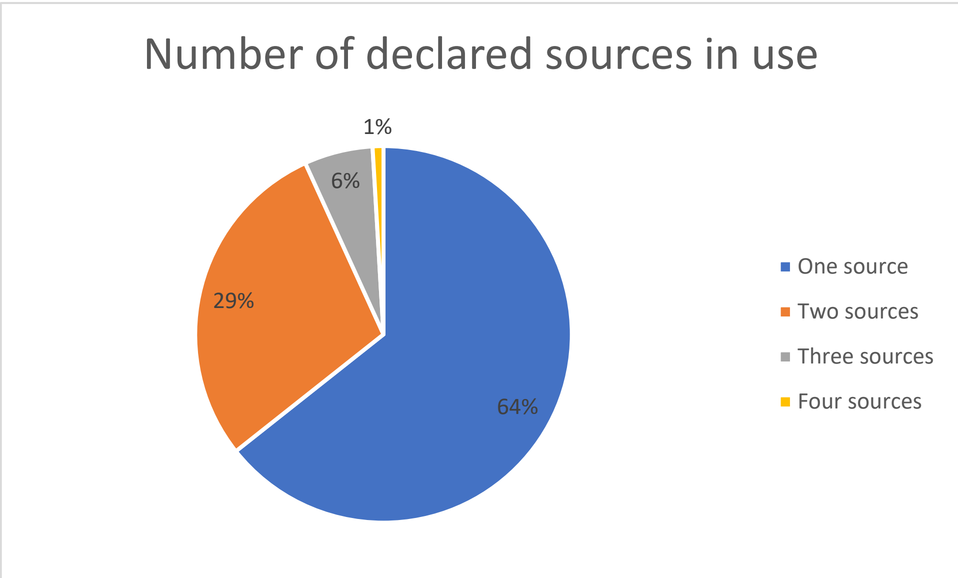


Figure 26 Number of declared sources in use.

If there is only one heat source installed in a building and it is in operation then solid fuel boilers are the most popular. The next most common are fireplaces, electric heating and heat pumps. Most of these are designed for space heating and hot water at the same time. Only in the case of fireplaces and tiled stoves the vast majority are used only for heating. In the case of two installed sources usually both are in use. Most often it then concerns a combination of a fireplace with electric heating. When three sources of heat are installed then in most cases all three are in use. The most common combination then is a solid fuel boiler (automatic feeding), with a fireplace and electric heating. Similarly, with the four sources given, most often all are declared as in use.

When it comes to solid fuel boilers, the largest number in use are boilers classified as below class 3 or without specifying any class (the percentage is presented in Figure 27). The most commonly specified are

Class 5 boilers, which are newer-generation devices that are considered greener due to their lower emissions than classic coal-fired boilers.

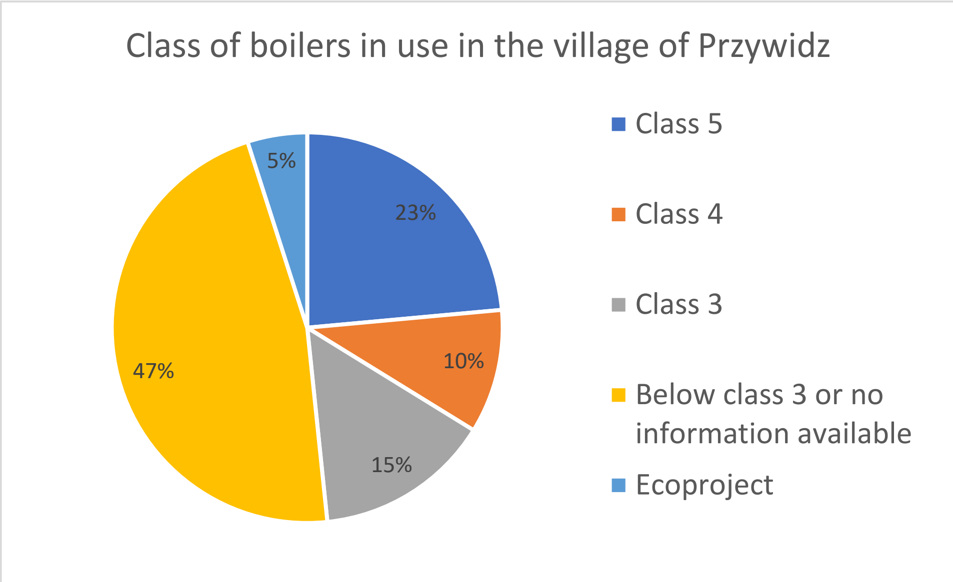


Figure 27 Class of boilers in use in the village of Przywidz.

There are differences in how each type of source is used. The most common use of the source is for heating and hot water heating simultaneously. In Przywidz for this purpose, the most popular is the use of solid fuel boilers with both automatic and manual feeding. For space heating alone the use of a fireplace dominates. This is followed by the usage of tiled stoves, both types of solid fuel boilers and electric heating at a similar level. For obtaining domestic hot water, electric heating and solar panels are used most often. More than 20% of all fireplaces and 16% of tiled stoves identified as in operation have no reported household function.

3.6.2 Estimation of heat requirements in Przywidz

The central statistical office publishes data on country level, the CEEB database gives some information regarding used energy carriers, but the amount of heat needed for the household or Przywidz is still not known. Estimating the heat requirements of residential buildings is not a trivial task. There is very little data on the sources that people use – the CEEB-database just started collecting data in 2022 and in its first iteration is not without problems. In addition, there is no data from individuals on the fuels purchased, and, as there is for example no gas network, even trying to get a top down view from e.g. a supplied amount from a service supplier is not an option. People also can have wood stoves or can burn waste, which would not at all be visible in fuel-purchase statistics. As such, it was necessary to resort to estimates from available data on buildings and population.

The procedure to estimate heat requirements was developed in the Fluid-Flow Machinery Institute within the Biostrateg project called 'Techrol TechRol Nowe technologie eko-energetyczne dla zrównoważonego rozwoju obszarów wiejskichi niskoemisyjnej produkcji rolnej' [10]. The municipality Przywidz provided a spatial dataset with buildings and allotments. This was matched with the national topographic database (BDoT10k) [11], in order to have maximal information on the buildings: number of floors and function. The spatial datasets themselves contain the geometries of the buildings, and as such encompass their location and size. Statistics exist to estimate the heat requirements for a building, depending on its type (residential, single/multi-family, ...), its age and its size. Type and size are available in the building dataset, but unfortunately age was not; for age we used a weighted average based on the statistics of the ages of buildings in Poland. This should limit the error when multiple buildings are aggregated. The assumption was made that all buildings constructed after year 2000 are isolated and they have an average heat usage of 90 kWh/m^2 yearly. There are reports claiming that 32% of buildings in the rural areas has no isolation [12]. In this analysis it was assumed that 35% of the buildings is not isolated and their yearly heat requirement is 160 kWh/m2, and that 65% of buildings is isolated and has a heat usage of 100kWh/m^2. For the non-residential but heated buildings we assume the usage of 130 kWh/m^2. The procedure was to estimation the heat requirement for each building based on the available data. The objects such as free-standing garages or sheds are considered to be not heated.

The above procedure assumes that the building dataset is quite accurate. In order to verify the above calculations, the heat estimate was also calculated differently. There are statistics on how much heat a household annually requires. As an alternative procedure, the population density grid (a 1x1km grid) was sourced and adapted to the municipality Przywidz (the cells for the grid do not overlap perfectly with the administrative borders). Subsequently, this grid was redistributed over the residential buildings in the municipality. Here, a severe discrepancy came to light: the amount of residential floor area per person was unrealistically below the national rural average (somewhere between 50 and 60 m^2).

An on-site survey combined with information from the local partner revealed that the national database contained incorrect data regarding the number of floors of the buildings. In addition, information of the partner Przywidz gave insights in buildings that were missing from the national databases. Those buildings were present in OpenStreetMap [13]. Using this knowledge, a corrected building-dataset was generated by merging data from BDOT with OpenStreetMap and correcting the number of floors for the buildings (as many buildings in Przywidz have a similar height, this correction could be made quite quickly based on some general assumptions). This corrected building dataset should now contain a realistic assessment of the total residential floor area, and can be used in the heat estimation. Based on that it was possible to define for each building its heat requirement (an example of such dataset is presented in Figure 28) and calculate the overall needs of the municipality for heat.

Figure 28 The estimation of heat needs for buildings in Przywidz municipality.

Table 8. Sum of yearly usage of heat in Przywidz municipality based on the analysis from [10].

Categories of buildings	Yearly usage [MWh]
Residential buildings	27 763.88
All buildings	29 018824

The next step was to estimate the distribution of the heating needs over the statistical year. The demand for heat changes with the temperature change if it is warm during the day and the temperature drops only at night, the heating will not be switched on for a short time. Half-hour resolution data is enough to perform such smoothing. To estimate the demand, we use daily averages - if the average is higher than 16° C, we assume that the heating was not turned on that day and the only consumption that occurs is heating of utility water. The approach is based on a very simple model of the relationship between heat demand and outdoor temperature - the relationship is linear with a cut-off at 16°C and a consumption of up to 60 kWh per day at -20 °C. Such calculations were combined with the heat estimates for each building. This allows to estimate the share of the heat required for each month of the year. An example of average household consumption for 2018 data is shown in Figure 29.

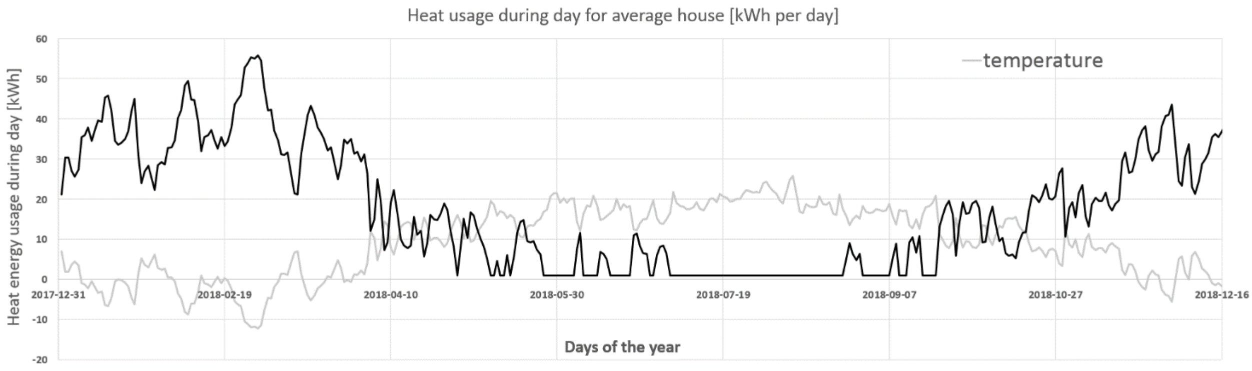


Figure 29 Estimated need for the heat for statistical household during a year.

Such a distribution was required to analyze the potential development of more ecological heat sources in Przywidz, especially towards the development of carbon free heat sources.

Looking at the statistics of heat sources in Przywidz, it can be seen that only a few percent of households today use heat pumps as sources of heat and hot water. The vast majority – about 70% – still burns solid fuels in fireplaces and boilers. Therefore, there is still a great need and potential for the popularisation of heat pumps as a form of local heat and hot water production, especially since the growing number of photovoltaic installations in the municipality can be seen. This, combined with heat and electricity storage facilities, can be a great way for local decarbonization.

The technologies demonstrated in the project, such as heat pumps, are already used in the community, but still to a very small extent. It is necessary to increase the interest of residents in this form of heat and hot water production, especially since there is no district heating in the municipality. As shown by the large number of photovoltaic micro-installations in the community (1670 kWp installed), the inhabitants are open to new technologies. The support of the municipality greatly accelerates the changes, , thanks to raising awareness and helping in obtaining funds for this goal.

The fuels used locally are mainly fossil fuels (coal and, to a marginal extent, gas and fuel oil) but also biomass of various origins. Although the use of biomass is not directly the subject of interest of the SERENE project, taking into account the rural character of Przywidz and the local fuel production, it seems reasonable to also present this potential. Biomass will certainly not disappear from some local households as a fuel, and with the use of newer boilers and/or flue gas cleaning systems, it can also be part of a strategy towards decarbonization.

Gmina Przywidz is a rural community, with a reasonable amount of agricultural activity. This activity results in biomass, which, according to some interpretations, can also be a fuel-source that helps with decarbonisation. As such, we also evaluated the biomass that could be available for this purpose. Based on the work of Pudełko et al. [14], [15] the assumption was made that the potential of local biomass in the form of straw and wood would be used for the analyses.

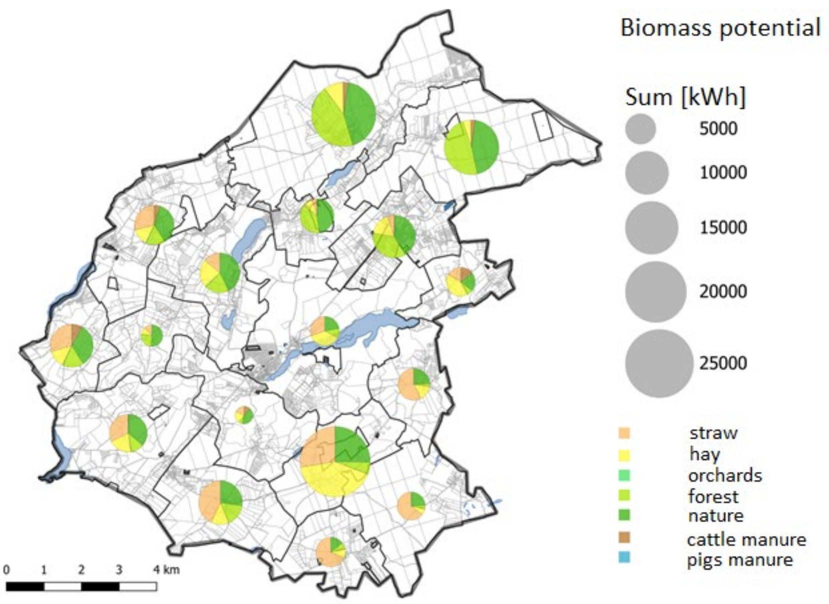


Figure 30 Potential of biomass with division to the precinct and types of biomass.

The analyses presented in the Figure 30 are optimistic in the sense that it considers 100% of the locally available biomass in the form of straw and wood. The sum of biomass from the forests are estimated to 9613.1 MWh, from the area NATURA: 14805.9 and from the straw: 9463.7 MWh. This is optimistic as straw competes with local agricultural production, while wood biomass can also be used for other purposes. In addition, it was necessary to take into account the fact that part of this potential biomass is already used for heat production (approx. 30%). This means that there is an additional 9463.7MWh + 9613.1MWh + 14805.9MWh - 11105.6MWh (already used biomass) = 18045.3MWh in potential fuel. Due to its nature, it is easier to use biomass where it is produced. From previous studies it is known that if 100% of the potential biomass from local resources is used, it is able to cover 78.7% of the total demand for heating individual houses in Przywidz. To provide 100% heat for houses by replacing fossil fuels with biomass, the remaining 7,497.5MWh in fuel (biomass) would have to be imported. As such, the available biomass would not be sufficient to cover the most appropriate places for its application as a heat source.

3.7 Energy needs and usage – electricity

The electricity consumption is considered sensitive data, so it was not possible to obtain the detailed usage for the area of Przywidz Municipality. The central statistical office publishes aggregated data for the different types of consumers (Figure 31) or the averaged data per household. According to GUS, the average usage of electricity in a standard household is 2173 kWh per year, with median of 1990 kWh per year, per person the statistical energy usage is estimated to 769.7 kWh/year. The differences in the usage are the effect of the differences in household appliances and the lifestyle of the inhabitants. The detailed usage data have to be obtained on a case by case basis, and is only possible if the owner of the building signs a consent form. The Energa Operator SA provided the percentage of users in the tariff groups: in tariff G are 54% of all energy users (this is tariff for households), tariff B – 18% (companies connected to the medium-voltage grid) and tariff C – 28% (companies connected to the low-voltage grid).

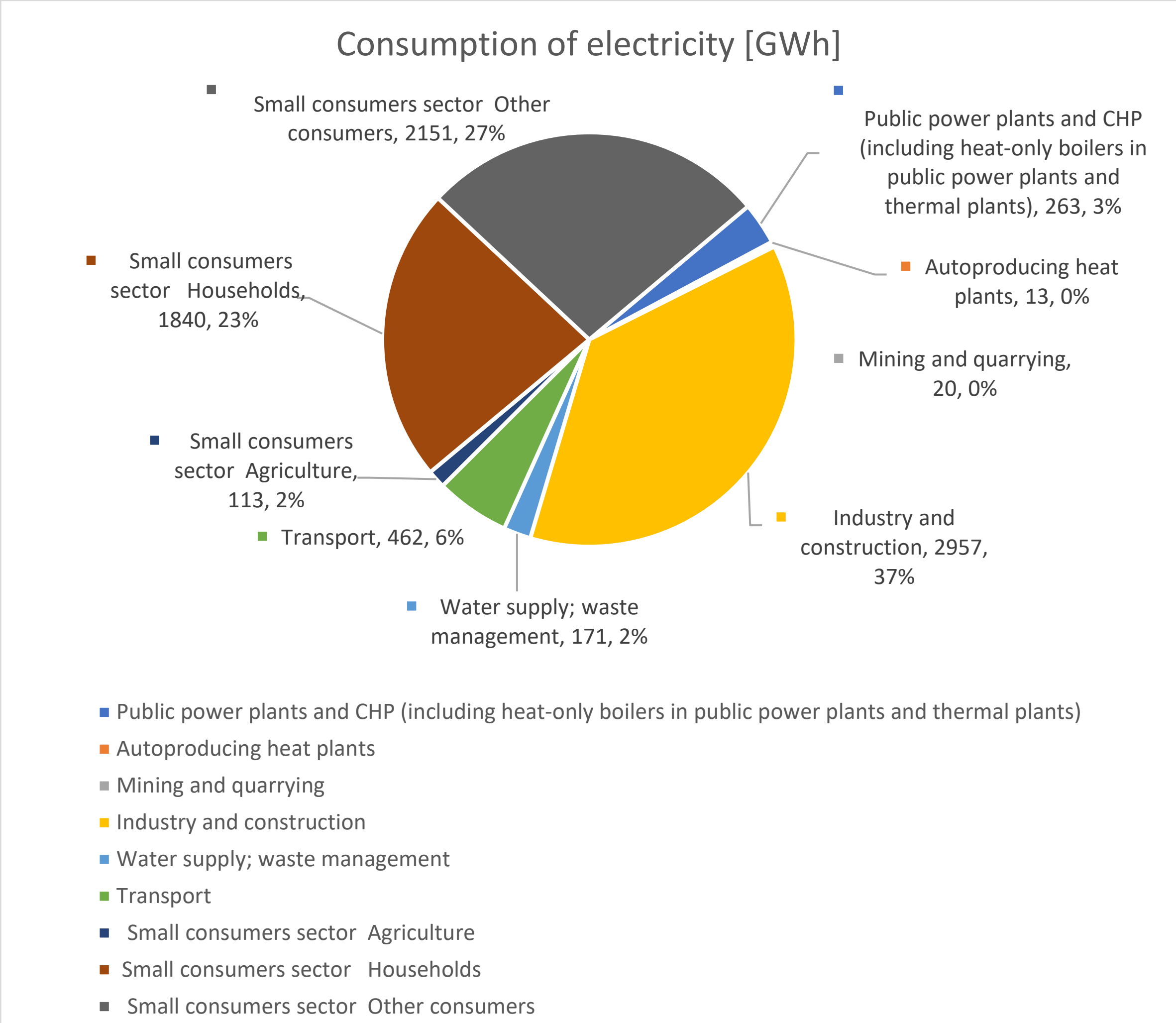


Figure 31 The consumption of electricity in Pomorskie.

Electricity prices are steadily growing in Poland with exception of 2019 where the government enforced changes in the energy market, to protect the community from raising energy prices. The Eurostat data for the average price of electricity for medium sized households is presented in Figure 32 [16]. The data are only available till the first half of 2022. In Poland, because of the political situation in Ukraine, the prices became unstable in 2022. The government did not allow electricity price changes for households in 2022. This was not the case for the companies, which caused problems as for some of them the price quadrupled. In order to restrict the price increase for households in 2023, the government no longer prevented price changes as they did in 2022 but instead introduced a limit-mechanism: the price for energy used below a specified limit is fixed; whereas the price for energy exceeding the limit-value will be calculated using the more expensive market price of electricity. This limit is set at 2000 kWh per year, with a higher limit of 3000 KWh per year for households with a Big Family Card or for farmers. In Figure 33 the prices for the most common single-zone G11 tariff for years 2020 till 2023 are presented.

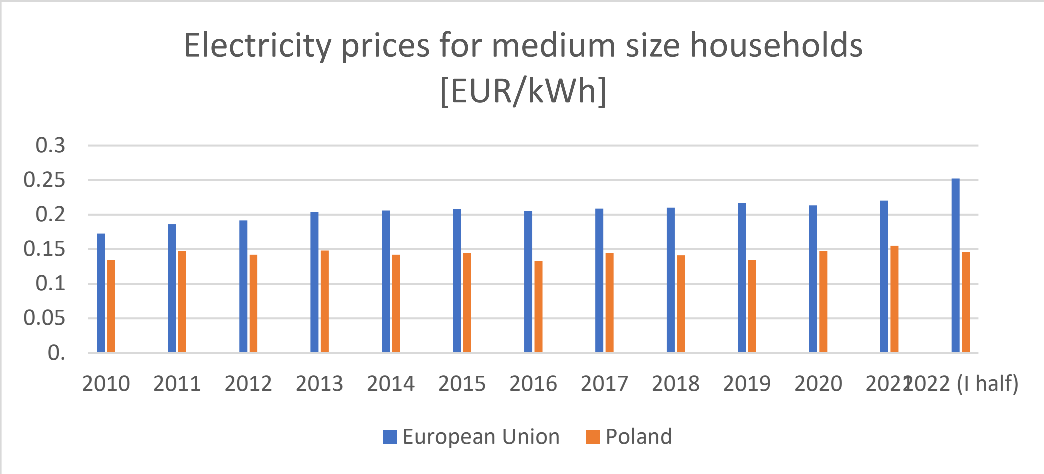


Figure 32 Eurostat data for energy prices.

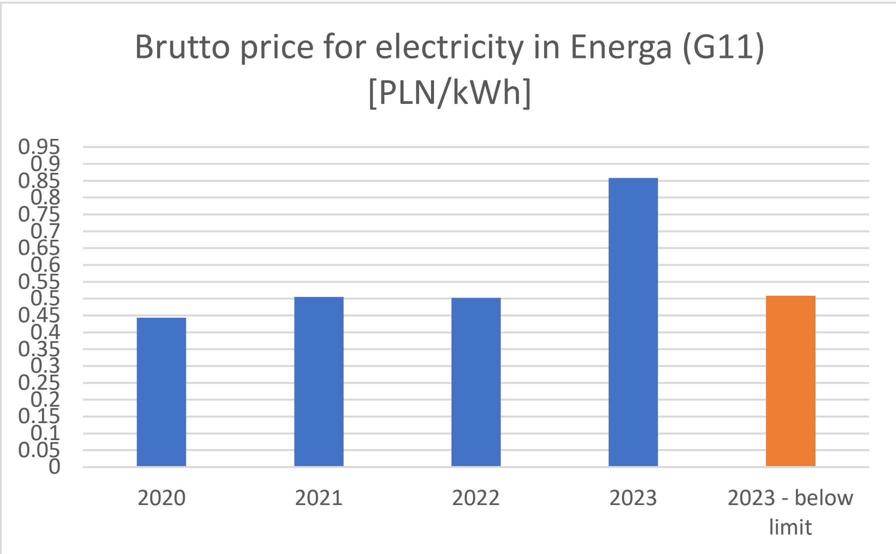


Figure 33 The electricity prices in Energa Obrót S.A for G11 tariff, for 2023 showing both the prices below and above the fixed-price limit to restrict electricity prices.

4 Development of Renewable Energy in Poland

In February 2021, Poland's Energy Policy 2040 (PEP 2040) was approved. The PEP 2040 represents a national contribution to the implementation of the EU's climate and energy policy. The increased role of renewable energy sources is driven by the need for a low-carbon energy transition through diversifying the energy portfolio and decarbonizing it. According to the plans outlined in it, the share of coal in the energy mix is to fall below 56% by 2030, while RES should increase to at least 23%. Moreover, in 2040, up to half of the energy generated in Poland should come from clean sources. For this purpose, nuclear power and offshore wind power in the Baltic Sea have been recognized as strategic elements of future development. The installed wind power capacity is planned to reach about 5.9 GW in 2030 and 11 GW in 2040. The first offshore wind farm is expected to begin operation at the end of 2025. Along with the construction of the power plant, it is also necessary to expand the transmission networks in the northern part of the country and provide a major terminal (seaport) to handle the supply of necessary components.

4.1 Wind energy

Nowadays, a significant share of Poland's RES comes from wind power. In the beginning, it developed very dynamically. In 2013, Poland was even ranked ninth among European Union countries in terms of installed wind power capacity. In 2015, wind turbines in Poland generated more than 10,000 GWh of energy and this was an increase of 40% compared to the previous year's performance. Unfortunately, the situation changed in 2016 [17]. The main reason for this was the introduction of the distance law, the so-called '10H rule'. Its main task was to define the minimum distance at which it is allowed to install wind turbines from households. According to the regulation in Article 4 of the Act, this distance had to be equal to or greater than ten times the height of the wind turbine measured from ground level to the highest point of the structure (including the blades). It also applies to the distance from the borders of national parks, scenic parks, nature reserves and Natura 2000 areas. The Polish Wind Energy Association determined that the amendment resulted in the exclusion of 99% of the country's area from the possibility of new construction. This has caused a practically total freeze in wind energy development [18]. Other problems in the expansion of wind farms included a change in the definition of a building plot, which resulted in additional taxes being placed on investors [19]. In addition, there was an oversupply of green certificates causing very low and fluctuating prices.

All of this has led to a lack of new wind power investments in Poland over the past few years. The discussions about changing the law continued for many years, but did not bring any solution. The first changes did not appear until 2022. In December 2022, the government adopted an auto-amendment to the bill, which allows local communities to participate in the benefits of locating a wind power plant in their district. According to it, the investor of such a power plant will share at least 10 percent of the installed capacity for the benefit of the residents of a given municipality under the formula of a virtual prosumer. A virtual prosumer is defined within the Renewable Energy Act and is defined as an end user who generates energy outside the place where he consumes it. Work on the amendment of the 10H Act is still in progress. However, it should be emphasized that the implementation of the wind power amendments is one of the 37 milestones that Poland has to meet in order to meet the requirements under the Reconstruction and Resilience Instrument to release funds from the National Reconstruction Plan [20].

The legal regulation of the development of offshore wind energy in the Baltic Sea is established by the Act of December 17, 2020 on the Promotion of Electricity Generation in Offshore Wind Farms. It includes regulations relevant to the development of offshore wind farms: the support system, the local supply chain and the grid connection; it also introduces a number of procedural improvements in construction and operation, as well as administrative proceedings to speed up investment [21]. For offshore wind farms, the 10 H rule does not apply. However, other problems occur; the biggest is the time needed to implement an investment: the issuance of permits for offshore wind energy takes quite some time. Administrative procedures are very dispersed, which contributes to this, together with the need to conduct several geological studies. Currently, 11 areas have been determined for which applications for permits to build farms can be submitted [22].

4.2 Photovoltaic energy

The growth of photovoltaics (PV) in Poland began in 2011 and its progress has been much faster than initially expected. In 2010, it was forecast that 1.8 GW of installed photovoltaic capacity would be reached in 2020 and by then it was already over 3.9 GW [23]. A significant increase in new installations was seen from 2019. The highest rise occurred in 2021, when the capacity of new installations was 3.7 GW and the total connected load was 7.7GW. The sudden increase in energy generated from solar panels at the end of 2021 was due to the announcements of a change in billing for those setting up PV from April 2022. Microinstallations dominate in Poland. Their total installed capacity was more than 6 GW in 2021. Other installations, small (50 kW - 1 MW) and PV farms (above 1 MW) contribute only about 1.7 GW of installed PV capacity. By the beginning of 2022, PV represented the largest share of RES at 50% of the total capacity.

In 2015, the Renewable Energy Sources Act was passed in Poland, which is the foundation for photovoltaic in Poland. It has been amended many times over the years; as many as 20 times between 2019 and 2021 alone. One of the reasons was the need to adapt the Polish Energy Law to EU regulations such as the RED II Directive (2021). The main goal of its establishment was to increase the share of renewable energy in the sectors such as electricity, transport, heating and cooling by 2030. It specifies that at least 32% of energy must come from RES. Poland, as part of the RED II implementation, has introduced a clause in the Energy Law that also allows contracting of energy based on PPAs - Power Purchase Agreements. This gives the end user the opportunity to purchase electricity directly from the producer at a fixed price throughout the term of the contract. Another important change was to raise the qualification level of a ‘small installation’ to the range of 0.5 MW - 1 MW of total installed electric power. This makes licensing mandatory for installations above 1 MW.

In order to encourage households or smaller businesses that generate electricity for their own needs to invest in RES, the ‘Prosument’ program was created. A prosumer is a person who uses and produces energy from their own RES installation up to 50 kWp. It is a consumer and producer at the same time. Any excess energy produced can be injected to the grid. Until April 2022, this worked under the net-metering procedure. According to it, a prosumer who inject his produced energy into the grid could receive a discount. Within a year, a prosumer had the opportunity to draw 80% of the energy they injected to the grid if they had a micro-installation up to 10 kW (or 70% for larger installations). Currently, the energy obtained from photovoltaic is settled by net billing on the basis of buying and selling overproduced energy. The prosumer sells electricity at the market price using dynamic tariffs according to hourly prices, but buys it the same way as any consumer, along with a distribution fee, other fees and taxes. Unfortunately, this results in much higher energy purchase prices than energy sales-prices for the prosumer. Electricity prices in Poland are set by the Energy Regulatory Office.

The ‘My Electricity’ program has been operating in Poland since 2018. It consists of a non-refundable financial aid for a household to install a photovoltaic system in order to encourage investment in renewable energy sources. Subsidies for photovoltaics are expected to result in greater development of photovoltaics, which will later improve air quality and reduce greenhouse gas emissions by reducing the amount of energy produced from conventional sources. The fourth edition of this program began in April 2022. In addition, funding is now provided not only for photovoltaic installations but also for energy storage, both heat and electricity and for systems for managing energy. Both existing and new prosumers operating under different accounting systems are eligible to participate. The goal of the 4.0 version program is to increase self-consumption of photovoltaic energy by storing surplus energy in storage facilities, as well as to increase the efficiency of energy management through HEMS/EMS systems.

The expansion of power storage facilities will contribute to reducing the load on the power grid as well. However, they are held back in development as the power storage capacity is added to the capacity of the installation when estimating the potential impact of the installation on the grid. Poland's distribution networks are outdated. ClientEarth has published a report regarding the situation in Poland. In it, they stress that almost 40% of network components is more than 40 years old. Transmission lines were not designed for high, temporary overloads caused by sudden production from RES, which can lead to excessive voltage or frequency in the grid or to thermal overloads. The consequences of this are damage to the transmission system, destabilization of the grid itself and a decline in the quality of electricity. If we want to be able to connect new investments to the grid, it is necessary to modernize it. The total available connection capacity for the next five years will be in the range of 6-8 GW. Comparing the current plans with those issued by the distribution network operator a year ago shows a decrease in capacity by half. This illustrates the condition of the power grid, while showing the growing problems in this area. In addition, there was a visible increase in the number of declines in conditions for connection for new projects in 2021. In total, for the 6 largest grid operators (transmission and distribution), the total capacity of refusals increased from 457 MW to 25 667 MW. As a result, grid access has become a barrier and constraint to the development of photovoltaics and energy transition in 2022.

Through the Renewable Energy Act in 2015, a price auction system was introduced. This is a support system for renewable energy sources, which operated from 2016 to 2021. In this context, the Energy Regulatory Office held auctions in which participating investors competed with each other, stating the price they wanted to obtain. The winners of the auctions were guaranteed a fixed revenue from each MWh generated for the next 15 years. The auction system, in its six-year cycle, provided certainty and profitability for investments in photovoltaic farms. However, in recent auctions, producers did not offer the entire volumes, but only part of them. This is due to the increase in energy market prices, which are higher than those in auctions, making investors prefer this form of energy sales. The first six-year period ended in December. On November 30, 2021, the European Commission announced a positive decision on extending the scheme for the period 2022-2027.

With the aim of increasing the share of RES and accelerating the energy transition, several directives and supporting packages are being introduced. In 2019, the European Green Deal program was presented, with the main goal of reducing greenhouse gas emissions by at least 55 percent net by 2030 compared to 1990 levels and achieving zero net greenhouse gas emissions by 2050. In 2021, the Fit for 55 package was introduced, focusing on accelerating the energy transition. In 2022, the REPowerEU [24] plan was announced to make Europe independent from Russian fossil fuels, in particular gas, before 2030. This is expected to increase the EU's energy security. The biggest beneficiary of REPowerEU potentially is the photovoltaic sector, through the EU Solar Strategy for the exploitation of the potential of photovoltaics. REPowerEU is based on the Fit For 55 package and does not change its key assumptions. However, the strategy proposes increasing renewable energy targets, with the share of renewables in final energy consumption set to rise from 40% to 45% in 2030. The EU strategy also aims to increase the number of photovoltaic energy installations. More than 320 GW of new photovoltaic installations are to be built by 2025, more than twice as much as today, and by 2030 this is to increase to nearly 600 GW. To achieve this, the strategy outlines the European Solar Rooftop Initiative as one of its measures. The Solar Rooftop

Initiative proposes to make it legally mandatory to install solar panels on public, commercial and residential buildings.

5 Energy communities in Europe

Recently the potential of the bottom-up activities to tackle climate change are noticed and supported. The idea is to facilitate the groups that care about their local community and are willing to do investments in cleaner and more sustainable energy sources. The Rescoop.eu project is the federation of citizen energy cooperatives that promote and develop social energy and energy communities. According to their publications [25] social energy is the key to tackling the climate crisis, developing local economies and revitalizing communities. It can help bridge the gap in living standards between urban and rural areas. The implementation of social energy activities leads to energy democracy, as it creates collaborative economies and societies as a result.

The world is facing several crises at once: climate, health, economy, society and democracy, all of which are interconnected. Traditionally, the energy system is a matter of large corporations that are bound by tight regulations to guarantee stability and security. In this context, the possible input from citizens is rather limited, at most they can choose between energy operators. The technological advancements has been turning this system around: people have the possibility to become prosumers, by for example, install ing photovoltaics at home and becoming a more active player in the energy system. The slow pace of changes in the central system, partly caused by technological limitations as power quality has to be maintained, partly by corporations' reluctance to invest, but also not in a small part by legal restrictions from national laws, makes people feel disillusioned. There is a feeling of injustice as the citizens are impacted by the climate crisis, while getting the impression that their efforts to mitigate the crisis is actively countered. The problem is often only approached from a social point of view, but other aspects - technical, legal, economical- should not be ignored.

The added value a single household can provide to the energy system is limited: private photovoltaic installations have limited power and the grid has to be adjusted to deal with power being put on it. This is where the concept of energy communities has a potential: it is not only a social aspect, but it allows to increase the impact by grouping prosumers (consumer-producers, such as a house with photovoltaics) to increase their overall contribution, and help mitigate problems for the energy system that are easier to resolve due to the change of scale and expansion of the range of solutions. Depending on the energy infrastructure in the country, the energy transition is not straight forward and energy communities may be a way to facilitate it. The Polish demonstrators in the SERENE project have the full support of Energa Operator SA; this partner not only helps to highlight the problems but also helps to develop/design solutions that aim to overcome the technical hurdles (Use Case 1 in particular aims to tackle issues with multiple residential photovoltaic installation). In addition, in many countries, for example in Poland, there are also many legal barriers that prevent proper creation and operation of energy communities. The Polish lawmakers have already made some changes but several issues still remain. However, unlike technical issues, such aspects can change relatively fast.

There is now a consensus that the energy systems have to change to manage with the changing reality and deal with the climate change [26]. The complexity of climate change and the need to adopt the principle of climate justice are presented on the website www.climatejusticesyllabus.org.There is a need to limit burning of fossil fuels that are damaging the climate, and move to renewable energy. Switch to

100% renewable energy is equated with moving to fully decentralized systems. The power generation itself can be decentralized – as happens with domestic photovoltaic installations – but there still needs to be a central point that is capable of intervening in order to guarantee the power supply and the power quality. The move to 100% renewables is commendable and should be the target, but one should not ignore practical aspects: cold areas with less sun in winter and less wind will have it more difficult to find renewable sources. In all cases, due to the variable nature of renewable sources, energy storage becomes of greater importance as well, as energy generation not necessarily happens at times when energy is required.

The legal barriers require actions from politicians and pressure from the population as well as input from involved parties can help remove these barriers. In this context, the social energy initiative is important as it creates a single, louder voice than individuals can provide. Involvement in the social energy initiative creates the opportunity to introduce changes in the community, and start a local energy transformation.

Examples of social communities are presented and promoted by the European Federation of Citizens' Energy Cooperatives (REScoop.eu, [25]). The authors present a number of publications where they list the advantages of social power:

1. Building a system that will contribute to stopping the climate crisis.
2. Funds previously supporting a fossil fuel based system are redirected to renewable energy projects and stay in the local community.
3. Reducing local energy poverty.
4. Strengthening the local community.
5. Production of renewable energy.
6. Educating the public about energy, climate and democracy.
7. Building a more local and more circular economy.
8. Creating a better world for ourselves and future generations.

5.1 The guidelines on the EU level

The new energy legislation adopted at the EU level in 2019 should help to develop social energy and implement related projects across Europe. European energy communities have been granted new rights to generate, use, sell and store renewable energy [27],which are:

1) Citizens and communities have been recognized as participants in the energy system.

Citizens, local authorities and small and medium-sized enterprises can set up legal entities to produce energy from renewable sources. These communities have been recognized as actors in the energy system and must be supported by the governments of EU Member States. As part of the activities of energy communities, citizens can generate financial resources by creating special purpose funds, the funds of which are distributed locally to provide services or cover local demand.

2) Citizens gained the right to produce, store, use and sell their own energy from renewable sources.

The citizen has the right to invest in the energy system. The government is required to ensure that citizens have these rights.

3) The government of the country must create a favorable legal framework to support citizens.

Each EU Member State is obliged to provide social energy with support from the legal system, e.g. by creating support mechanisms in obtaining funds for projects or appointing an agency providing advice and support, whose task would also be to develop rules for access to the electricity grid.

4) The country's government must simplify administrative procedures for civic and social projects.

One of the difficulties of creating social energy projects is the complexity of administrative procedures involving a lot of paperwork. However, thanks to the legislation adopted at the EU level, it is the government's duty to simplify the administrative procedures for civic and social projects.

5) The national government needs to assess the barriers and potential of social energy.

The government is also required to assess the barriers and potential of renewable energy communities in the country. This assessment was to be made by the end of summer 2021.

5.2 Forms of activity form a social point of view

Social energy can include collective campaigns to switch electricity supplier, collective investments in solar panels, heating, cooling, transport, but also ownership of an energy supply company or even a distribution network. In some cases, the cooperation of those involved in such activities is informal, while in others legal entities are created. Among the legal forms used to create local energy communities are: energy cooperatives, partnerships, companies acting for the benefit of the community, foundations, non-profit organizations, trusts and associations. The choice of legal form depends on the type of activity and on the laws in force in the country concerning cooperatives and other organizations.

A cooperative is a group of citizens working together to implement a given initiative for the benefit of the whole community. In Europe, many social energy projects are implemented by energy cooperatives dealing with the production of energy from renewable sources. The main purpose of the cooperative's existence is not to generate financial profits, but to strive to improve the life of the local community. This does not mean that cooperatives do not make a profit, but that profit is either used directly for the needs of the members of the cooperative or is reinvested in projects that benefit the natural, social or economic environment of the community. The cooperative is organized in a democratic, open and transparent way. This applies to both the internal organization and the financial decision-making process. For example, members can decide how the cooperative's profits are used, team building strategies and team activities. When making decisions, the voting principle applies, each member of the cooperative has one vote, regardless of the amount of funds invested by him.

There are several ways to organize the management of a cooperative. It is usually based on the seven principles set out by the International Cooperative Alliance (ICA) based on the Cooperative Principles (the so-called Rochdale Principles, named after the city of Rochdale where the world's first cooperative was founded):

- Voluntary and open membership.
- Democratic membership control.
- Member Economic Participation.
- Autonomy and independence.
- Education, training and information.
- Cooperation between cooperatives.

- Concern for the local community.

Although many countries have developed their own legislation defining the legal forms of cooperatives, the principles of the ICA can be incorporated into any legal framework (e.g. by writing them into statutes). Useful resources on cooperatives and social action can be found at [28].

In Europe, the most successful social energy projects are projects whose implementers cooperate with local authorities. Local or regional governments can gain a lot by increasing the scale of social energy projects in their area, and they can also initiate new projects themselves. Despite the growing popularity of this concept across Europe, many cities still struggle to move from idea to action. Many local governments have committed themselves to energy or climate targets. Ideas often come easy, but the execution is more complicated. This is where organizations such as Energy Cities come to the rescue, which is an excellent source of contacts and useful information (e.g. how cities can support communities producing renewable energy [29], or a study on the remunicipalization of energy sources [30]). ū

5.3 European Covenant of Mayors

The European Covenant of Mayors is a network of thousands of local authorities that have voluntarily committed to the EU's climate and energy goals. The signatories of the Covenant are required to send a plan of actions that are planned to be taken for sustainable energy and climate (SECAP). All local governments that have signed the Covenant of Mayors commit to three goals:

- accelerate the decarbonization process in their area,
- strengthening the capacity to adapt to inevitable climate change,
- enabling residents to access secure, sustainable and affordable energy.

Both co-operatives and local authorities are mission-driven and not profit-driven, so they share the same long-term goals. For example, in Belgium, several cities have acquired expertise and used the support of the energy cooperative Ecopower to develop and implement a Sustainable Energy and Climate Action Plan (SECAP). Community energy programs contribute to the implementation of climate goals, but also bring many local benefits. They help local and regional authorities:

  - improve energy efficiency and reduce the scale of energy poverty by creating opportunities to take advantage of cheaper tariffs or special programs to actively engage and support the most vulnerable consumers;
  - enable more active forms of local civic activity as these initiatives encourage residents to become more involved and considerate of their neighborhood and encourage them to participate in other sustainable activities such as recycling initiatives;
  - increase the dynamics of local economic development, as projects owned by members of the local community can contribute up to 8 times more to creating local added value.

The local government can support the development of social energy or be directly involved in activities in this area in many ways:

- Introducing favorable regulations for community and community energy - local and regional authorities can adopt special zoning or building regulations that will favor the development of energy sources owned by citizens or communities. For example, Barcelona is the first city in the world to adopt the ‘solar thermal regulation’ requiring owners of new and refurbished buildings to provide 60% solar-heated hot water.

- Raising Awareness - The more people are involved in energy related activities, the greater the understanding of the energy system as a whole. Local government can be a key player in understanding energy issues and encouraging citizens to participate in the energy transition [31].
- Purchasing electricity or heat from social entities – in order to cover the energy demand in all public utility buildings, local authorities may prefer 'green' but also 'social' energy purchases. This was the case with the city of Eeklo (Belgium), which commissioned the construction of a district heating network, with the requirement that the participation of residents in the project should be at least 30%.
- Financing and guaranteeing – one of the common barriers faced by community energy projects is access to credit. Local and regional authorities can be crucial when it comes to providing the guarantees required by financial institutions. They can also reassure undecided investors and give ventures additional credibility and legitimacy. Local authorities can also provide seed funding (e.g. through a revolving fund for social ventures) or allocate specific budget lines to support community groups at every stage, from the first feasibility and planning steps to actual infrastructure investments. Funded by the Scottish Government and managed by Local Energy Scotland, the CARES program provides grants to energy communities to finance a variety of business development activities. This includes, for example, feasibility studies, permitting procedures, community involvement efforts, and even covering the capital costs of renewable energy projects. When the project becomes a reality, these grants are turned into loans that are gradually repaid by the community.
- Providing staff and resources - local authorities can allocate specially designated space for the needs of social projects, e.g. by giving them access to the roofs of public buildings, they can provide access to municipal waste or other bioenergy carriers in the case of community heating projects. Another option is to provide experienced staff, as energy cooperatives often carry out their projects with the participation of inexperienced volunteers. In the UK, Plymouth City Council supported the creation of the Plymouth Energy Community (PEC) by delegating staff to develop a business plan and help recruit 100 founding members.
- Develop support platforms and tools - local and regional authorities can provide crucial support to community energy projects by developing specific support tools and programmes. Potential Inventory, or providing information on local renewable energy opportunities, is another simple way to help citizens and cooperatives get started.
- Facilitating dialogue between local stakeholders - authorities can be very helpful in bringing the community into contact with relevant economic operators and other entities dealing with social, environmental or energy issues in the area (e.g. energy agency or distribution system operator).
- Direct membership in the energy community - new EU legislation encourages local authorities to become effective members and stakeholders of energy communities along with citizens, but without taking full control.

6 Legal forms of energy communities in Poland

In Poland the discussions regarding implementing Red II directive and implementing the energy communities are still in progress. Currently, there are two possible legal forms of energy communities in Poland: energy cooperatives and energy clusters. Taking into account the still early stage of development of such forms of energy communities, it seems that for rural areas and local communities an energy cooperative will be a more adequate solution in Przywidz, hence more attention has been paid to it.

6.1 Energy cooperatives

An energy cooperative is a voluntary association of both civil and legal persons. The cooperative conducts its business activities based on the principles of economic calculation while providing benefits to the cooperative's members. Its assets are formed mainly from payments, other assets contributed by its members and also from income generated by the cooperative's activities.

An energy cooperative can be established in a rural or rural-urban area (according to polish categorization of municipalities) and it must be the area of a single electricity distribution system operator (DSO). An important requirement for establishing such a cooperative is that it must produce its own electricity covering at least 70% of its own demand. The main financial benefit of participating in a cooperative is a reduction in the price of electricity, as there are no RES, capacity or cogeneration fees charged for the energy generated and consumed within the cooperative.

Polish law specifies that the cooperative must produce energy only for their own use, with no possibility of selling to third parties. The situation is different when the cooperative generates electricity from Renewable Energy Sources. In that case, the Law on Renewable Energy Sources (RES) postulates that it is possible to trade off some of the electricity volume by inserting it into the electricity distribution grid and then taking it from the grid for the energy cooperative and its members' own consumption at a ratio of 1 to 0.6. It means that they provide 100% energy but can only collect 60% of it.

All accounts in the cooperative are carried out on the basis of data obtained from remote reading meters installed at all cooperative members, both generators and consumers of electricity. The data is retrieved on an hourly basis and collects information on the amount of electricity consumed and injected into the grid by all members. The rules are established in the Decree of the Minister of Climate and Environment from March 23, 2022 on the registration, balancing and sharing of the data and clearance of cooperatives accounts. To do so it is required to sign appropriate contracts. Among others, a comprehensive agreement between the seller and the energy cooperative. According to the Law on Renewable Energy Sources, the energy cooperative must have a distribution service agreement and an electricity sales agreement signed with the distribution system operator. In addition, according to the Energy Law, the distribution system operator must also sign a general distribution agreement with the seller.

Polish law is not adequately regulated. There are inconsistencies between some of the legal acts and some of the statements in the laws are not well unified. It is not specified what happens to customers' previous contracts after joining an energy cooperative. This could result in its members having different types of contracts with different vendors. This is against the principles of the cooperative, which should have one contract with a vendor for all members. In order to simplify the establishment and increase the efficiency of energy cooperatives in Poland the law and relevant acts should be clarified and standardized.

Poland currently has two cooperatives registered with the National Agricultural Support Center. In May 2021, the first one was created. It was the EISALL energy cooperative in the Mazowieckie Voivodeship. It has two photovoltaic installations of 10 kW each. The next was 'Nasza Energia' energy cooperative in Silesia province, which was created in December 2021, with seven installations with a total capacity of 51 kW.

Polish Power Transmission and Distribution Association (PTPiREE) has prepared a formula for a model that could be applied to the Polish energy market. The first requirement is to establish a single seller for the energy cooperative. The seller must sign a general distribution agreement for comprehensive contracts with the DSO. Energy consumers sign a comprehensive contract only with the seller. Generators must also sign an additional distribution agreement with the DSO for the energy generation. First of all, the accounts referred to in Article 38c (3) of the RES Act (Cooperative - Seller) shall be made by the Seller with individual cooperative members using the detailed rules specified in the Decree of the Minister of Climate and Environment dated March 23, 2022 on the registration, balancing and provision of metering data and settlements of energy cooperatives. Accounts between the DSO and the Seller shall be made for individual energy consumption points represented by energy cooperative members. Settlements between the DSO and the Seller include the absence of the RES, power and cogeneration fee in accordance with Article 38c(13) of the RES Act, with relation to the amount of energy generated and then consumed (including the amount settled in accordance with Article 38c(3)) determined as follows:

- $Ebs_{(t)}$ - the balance of energy for the cooperative - is calculated for each hour for the sum of all SE members:

$$Ebs(\mathrm{t}) = \sum_{k=1}^{n} \mathrm{Eb(t)\ (k)}$$

Where:

$Eb_{(t)} = Ep_{(t)} - Ew_{(t)}$

$Ep_{(t)}$ - energy consumed by the participant, $Ew_{(t)}$ – energy produced by the participant.

- Ebsp energy in the billing period is calculated, which is the deficiency of energy generated compared to that consumed:

$$Ebs\mathrm{p} = \sum_{k=1}^{n} \mathrm{Ebsp(t)\ (k)}$$

Where:

Ebsp – the sum of the volume of energy balanced at specific hours in the settlement period for which the balancing result Ebs(t) is positive

- the percentage of discount rate for the entire energy cooperative is calculated:

$\eta = Ebsp / Ep$

Where:

$$\mathrm{Ep} = \sum_{k=1}^{n} Ep(k)$$

Ep - the sum of energy consumed during the billing period by all members of the cooperative

- the DSO in the billing period for each energy consumption point representing an cooperative member takes into account the discount factor η when calculating the RES, power and cogeneration fee (reduces the abovementioned fees by the amount of the factor),
- if a member is paying capacity fees in flat-rates, then overall sum will be reduced by the amount of the discount rate η,

- the labeling of the mentioned symbols is in compliance with the Decree of the Minister of Climate and Environment from March 23, 2022 with the exception of the introduced new discount factor η.

The period of settlement for DSO - Seller billing is one month.

There is no schema or template for how the members of the cooperative decide of money transfers between them – it is not legally defined and the cooperative has freedom to create its own rules. Up to now there is no cooperative that needed to implement such an internal market. Many ideas can be applied, including those already known from literature regarding energy markets, e.g. block chain based approaches.

6.2 Energy clusters

Another option, that is possible for Poland, is energy clusters. As the RES Act says, clusters are 'A civil law agreement, which may include individuals, legal entities, research institutions or local government units, in relation to the generation and balancing of demand, distribution or trading of energy from renewable energy sources or other sources or fuels'. They operate within a distribution network with a voltage of up to 110 kV. Their area can cover a maximum of one county or five municipalities. The purpose of the clusters is aimed mainly towards assuring local energy security and reducing electricity costs. The reason for this is, among other things, that clusters are exempt from certain fees, such as the RES or cogeneration fee when balancing with the grid. They can generate, distribute and store electricity for their own use. Poland's Energy Policy (PEP) 2040 intends to have 300 such entities by 2030.

Each cluster must have a nominated energy cluster coordinator. This can be one of the members or a selected social organization. They are in charge of all legal and administrative issues related to the operation of the cluster. Members can be energy consumers as well as generators. Similarly to energy cooperatives, appropriate internal agreements are signed within the cluster operation and external contracts with the DSO. It is necessary to set up remote reading meters and perform effective energy balancing to ensure that the cluster is as self-sustaining as possible, without having to rely on the grid.

This is also the case where there are problems with regulations and their interpretations occurring in the national laws. One of the examples of this is the recent draft amendment to the RES Act (No. UC99 in the List of Legislative and Programmatic Works of the Council of Ministers), which is meant to bring the current regulations in line with the directive of the European Parliament and the Council - RED II. One of the problems is the proper calculation and establishment of price discounts between the various members, whose intake volumes vary considerably from each other. It also lacks a clearly defined benefits received after joining an energy cluster and information about source of funding for these changes. Many amendments and restrictions negatively affect the possibility of establishing new clusters. There has been a change that at least one of the members must be a local government unit. In addition, the new changes impose certain requirements on clusters. The new program is divided into two phases. The first part ends on December 31, 2026 and determines the maximum installed capacity of all installations in a cluster to 100 MW and requires that it must cover at least 40% of total demand. A minimum of 30% of all energy that is generated and distributed to the grid must come from RES, storage capacity should equal to a minimum of 2% of the installed capacity. The next stage elevates the requirements. The installed capacity will continue to be a maximum of 100 MW, while both the RES share and coverage of demand will have to increase up to 50%, and storage capacity to 5%.

Theoretically, several dozen energy clusters have been registered in Poland, but it seems that only a small part of them actually functions in business, and due to the involvement of private companies, access to information on how this cooperation looks like is very difficult. It seems that to this day, however, these are more agreements between local companies and large businesses and are not entirely focused on a single citizen.

The constantly changing law makes it very difficult to find, locate and secure the interests and needs of a citizen in this puzzle. For this reason, it seems that in the situation of looking for citizen-centered solutions and dedicated to local communities and not to the particular interests of investors, an energy cooperative may be a more adequate proposal at this point.

7 Technical analyses of Use Cases in Przywidz

7.1 Data gathered for the Przywidz Use Cases

Analysed period – UTC +0: 00:00 1.11.2021 – 23:00 31.10.2022, the data were aggregated to 1 measurement per hour. Value for 00:00 means average power from 00:00 to 01:00. The positive power values means that the installation is taking energy from the grid, the negative power values mean the power is generated and sent to the grid.

Use Case 1 covers the area of secondary substation number 5393 'Osada'. It contains around 100 measuring points, mainly households, 2 object belong to Municipality (Pump station and school/kindergarten on Cisowa street). As there was no possibility to install meters in all of the places, the data were provided by EOR, which anonymized the data. The households are described with the number to preserve the anonymity of the consumers. After analysis of data part of the measuring points were discarded as the data were not full or the usage was very low – one of the reason for this was that the object was not in use for the considered time range or there were some errors in the measuring system.

In order to expand the potential scenarios for the energy community few municipal buildings were added to the analysis: the municipal office (described in the graphs as Town Hall), Arena Przywidz (part of Use Case 2, described in the graphs as Sport Hall), School im. Unii Europejskiej (connected to the Arena Przywidz part of Use Case 2, described in the graphs as school) and the waste water treatment plant (part of Use Case 3, described in the graphs as WWTP). The municipality is very interested in being the active and core partner in the energy community, as values as: decarbonisation, increasing the energy efficiency, lowering the energy costs are the main highlights of the long term planning. What is more, the municipal buildings have no problem with data privacy, as the power usage of those is a public information.

To analyse the potential for energy community the data were gathered from 100 measuring points. 32 of measuring points are households and have a photovoltaic installation (4 installed in 2022, so the production does not occur for the whole year). Figure 35 presents the load duration curves for all of the considered installations. The x-axis is the amount of hours in which certain value of energy is consumed or produced, while the y-axis presents the averaged power for the single time unit (1-hour), the graph is ordered by the amount of hours the given power is used/produced. Such graph clearly shows that for a certain amount of hours the load did not dropped below some value or for certain amount of hours the production exceeded the consumption. The graphs in Figure 35 show the balance of energy, so there might be a situation that whole production of energy is immediately consumed by the installation and there is no surplus of energy in case of prosumers. Such situation is visible in case of waste water treatment plant (WWTP), where despite existing photovoltaic installation its production is almost completely consumed during the normal operation of the facility. The data sets for households from 1 till 30 have visible production from photovoltaics.

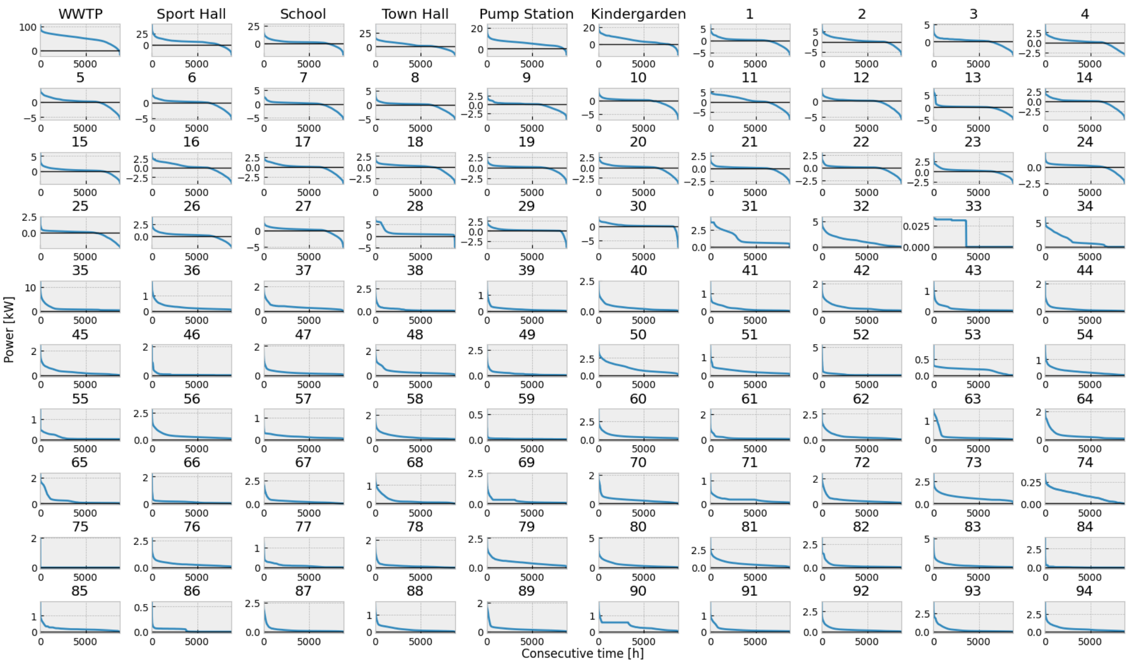


Figure 34 Load duration curves of all 100 measuring points.

To show the scale of the balance of energy the sum of consumption, production (over balance – injection of power to the grid) and the overall sum is presented in Table 8.

Table 8 Summary of the consumption and production of all 100 measuring points.

PPE	Consumed [kWh]	Injected [kWh]	Generated [kWh]	Used [kWh]	Sum [kWh]	Generation/Usage
WWTP	438033	-499	-57299	494833	437534	12%
Sport Hall	65590	-8966	-36592	93216	56624	39%
School	21864	-7814	-15032	29082	14050	52%
Town Hall	35018	-10117	-19407	44308	24901	44%
Pump Station	47755	-535	-17000	64220	47219	26%
Kindergarden	42034	-3163	-4650	43521	38871	11%
1	4722	-4737	-6767	6752	-15	100%
2	8575	-3801	-5430	10204	4774	53%
3	3936	-3335	-4764	5365	601	89%
4	3829	-2999	-4284	5114	830	84%
5	5409	-4616	-6594	7387	793	89%
6	3710	-4452	-6360	5618	-742	113%
7	3141	-4779	-6827	5189	-1638	132%
8	2902	-4853	-6933	4982	-1951	139%
9	2220	-3648	-5211	3783	-1427	138%
10	2135	-5332	-7617	4420	-3196	172%
11	12313	-6815	-9736	15234	5498	64%
12	2494	-5100	-7286	4680	-2606	156%
13	3158	-3951	-5644	4851	-793	116%
14	2283	-4010	-5729	4002	-1727	143%
15	4201	-2337	-3339	5203	1864	64%
16	5360	-3706	-5294	6948	1654	76%
17	3226	-3325	-4750	4651	-100	102%
18	2831	-2716	-3880	3995	116	97%
19	1936	-2419	-3456	2973	-483	116%
20	2466	-3226	-4609	3849	-761	120%
21	1699	-2113	-3019	2605	-414	116%
22	1268	-2493	-3561	2336	-1225	152%
23	2933	-1766	-2523	3690	1167	68%
24	1592	-2006	-2866	2452	-413	117%
25	1427	-2171	-3101	2357	-744	132%
26	3043	-1688	-2411	3766	1355	64%
27	3921	-3040	-4343	5224	880	83%
28	12013	-64	-91	12040	11948	1%
29	2402	-853	-1219	2768	1549	44%
30	4293	-990	-1414	4717	3302	30%
31	11385	0	0	11385	11385	0%
32	10588	0	0	10588	10588	0%
33	114	0	0	114	114	0%
34	10754	0	0	10754	10754	0%
35	8877	0	0	8877	8877	0%
36	2229	0	0	2229	2229	0%
37	2878	0	0	2878	2878	0%
38	1566	0	0	1566	1566	0%
39	1087	0	0	1087	1087	0%
40	2477	0	0	2477	2477	0%
41	1238	0	0	1238	1238	0%
42	2167	0	0	2167	2167	0%
43	1010	0	0	1010	1010	0%
44	1116	0	0	1116	1116	0%

45	2388	0	0	2388	2388	0%
46	427	0	0	427	427	0%
47	1554	0	0	1554	1554	0%
48	2534	0	0	2534	2534	0%
49	1383	0	0	1383	1383	0%
50	8958	0	0	8958	8958	0%
51	1984	0	0	1984	1984	0%
52	1011	0	0	1011	1011	0%
53	1437	0	0	1437	1437	0%
54	2033	0	0	2033	2033	0%
55	723	0	0	723	723	0%
56	2820	0	0	2820	2820	0%
57	1115	0	0	1115	1115	0%
58	1900	0	0	1900	1900	0%
59	84	0	0	84	84	0%
60	3744	0	0	3744	3744	0%
61	910	0	0	910	910	0%
62	2485	0	0	2485	2485	0%
63	1336	0	0	1336	1336	0%
64	2305	0	0	2305	2305	0%
65	2014	0	0	2014	2014	0%
66	915	0	0	915	915	0%
67	2091	0	0	2091	2091	0%
68	1460	0	0	1460	1460	0%
69	1751	0	0	1751	1751	0%
70	2219	0	0	2219	2219	0%
71	1381	0	0	1381	1381	0%
72	2313	0	0	2313	2313	0%
73	5890	0	0	5890	5890	0%
74	839	0	0	839	839	0%
75	2	0	0	2	2	0%
76	2695	0	0	2695	2695	0%
77	897	0	0	897	897	0%
78	1048	0	0	1048	1048	0%
79	3915	0	0	3915	3915	0%
80	4115	0	0	4115	4115	0%
81	4930	0	0	4930	4930	0%
82	1873	0	0	1873	1873	0%
83	3539	0	0	3539	3539	0%
84	428	0	0	428	428	0%
85	1582	0	0	1582	1582	0%
86	244	0	0	244	244	0%
87	1403	0	0	1403	1403	0%
88	1347	0	0	1347	1347	0%
89	1708	0	0	1708	1708	0%
90	2983	0	0	2983	2983	0%
91	1161	0	0	1161	1161	0%
92	2243	0	0	2243	2243	0%
93	2436	0	0	2436	2436	0%
94	3721	0	0	3721	3721	0%
Sum	927492	-128435	-289038	1088095	799055	27%

The values listed in the table cover all three analyzed areas (Use Case 1; Use Case 2; Use Case 3) in the demo in Przywidz. Individual cases based on aggregated values are presented below.

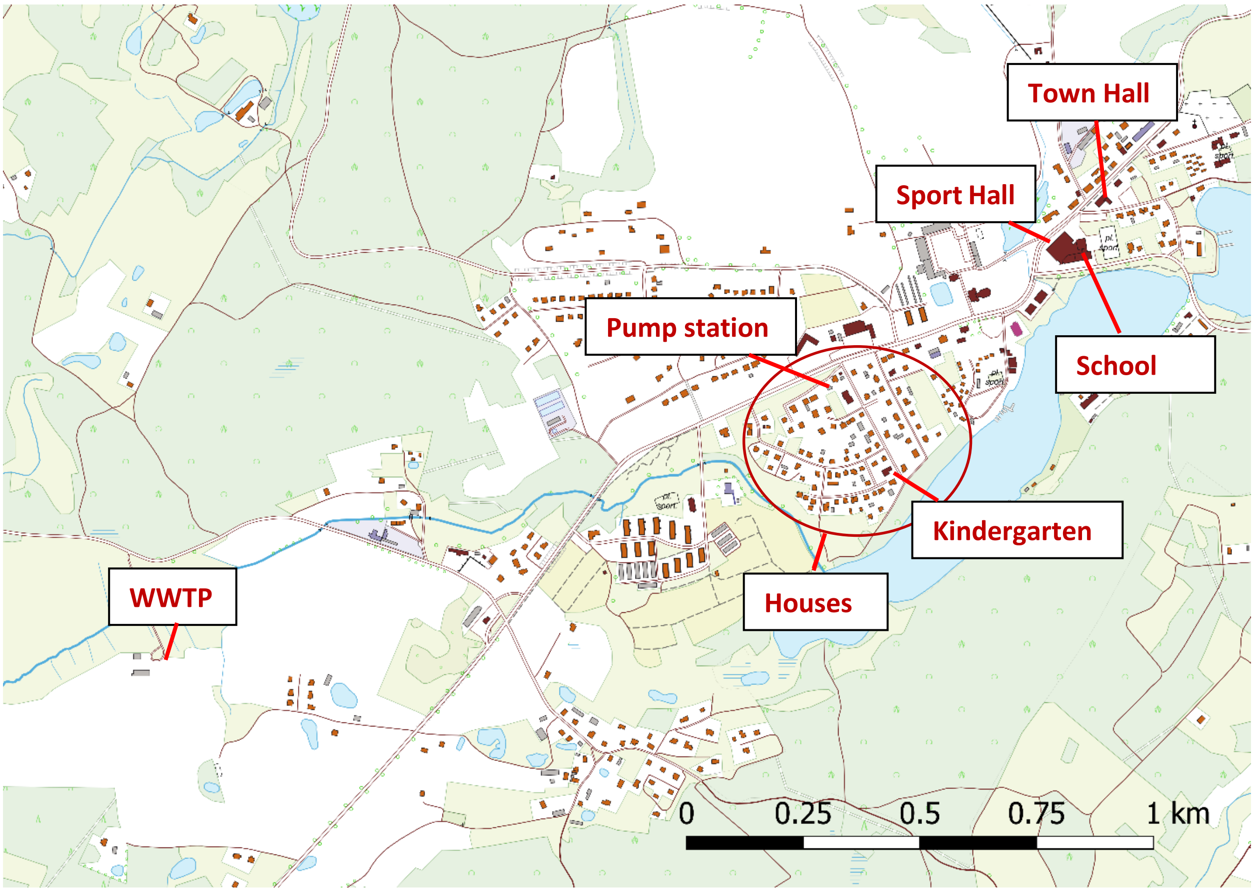


Figure 35 The approximated location of measuring points.

The load curves and load duration curves for all of the measuring point in Use Case 1 are presented in Figure 36. The top curve is presenting the data according to its time line (one measurement for each hour from UTC +0: 00:00 1.11.2021 to 23:00 31.10.2022). The bottom one is the load duration curve, where the power in 1-hour interval is sorted in descending order. The graphs show the aggregated values for the objects with photovoltaic installation (30 of the households, kindergarten and the pump station), objects that do not have photovoltaic installations and all of the installation. It is important to notice, that this graph considers balance in every 1-hour interval and because of the character of the graph the curves for measuring point with and without photovoltaic installations are not summing up to the curve of all the measuring point.

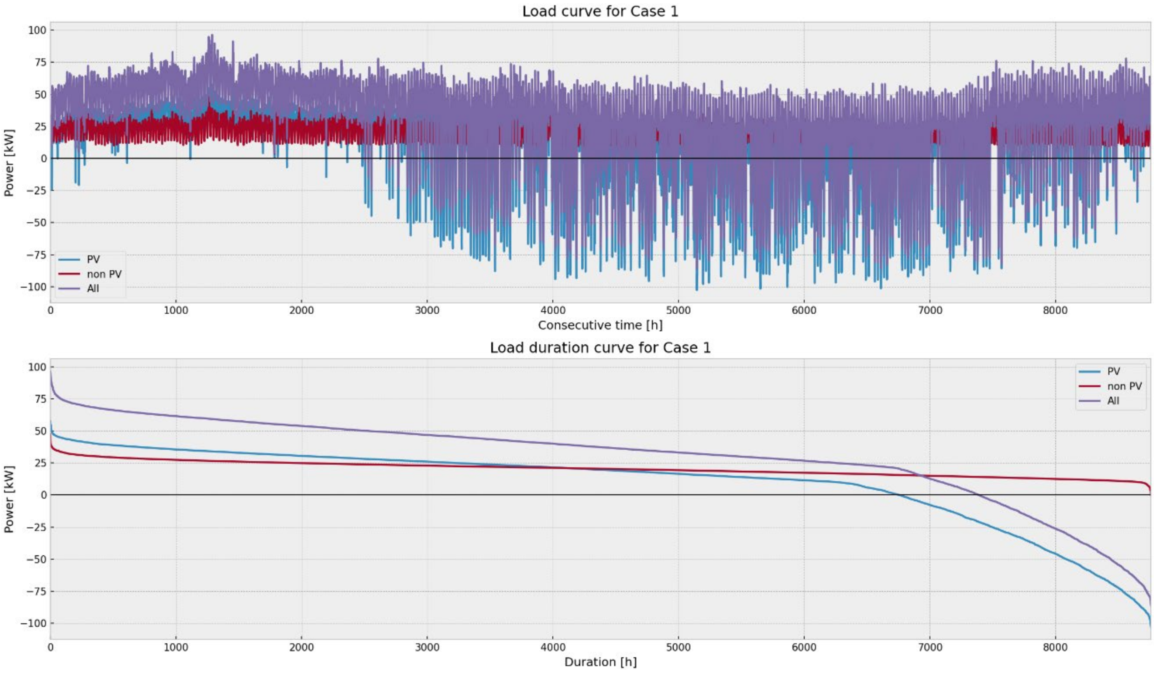


Figure 36 The load curves and load duration curves for the measuring points in Use Case 1.

Similar graphs (Figure 37) were made for the measuring point in Use Case 2- Arena Przywidz (sport hall) and the school im. Unii Europejskiej (school).

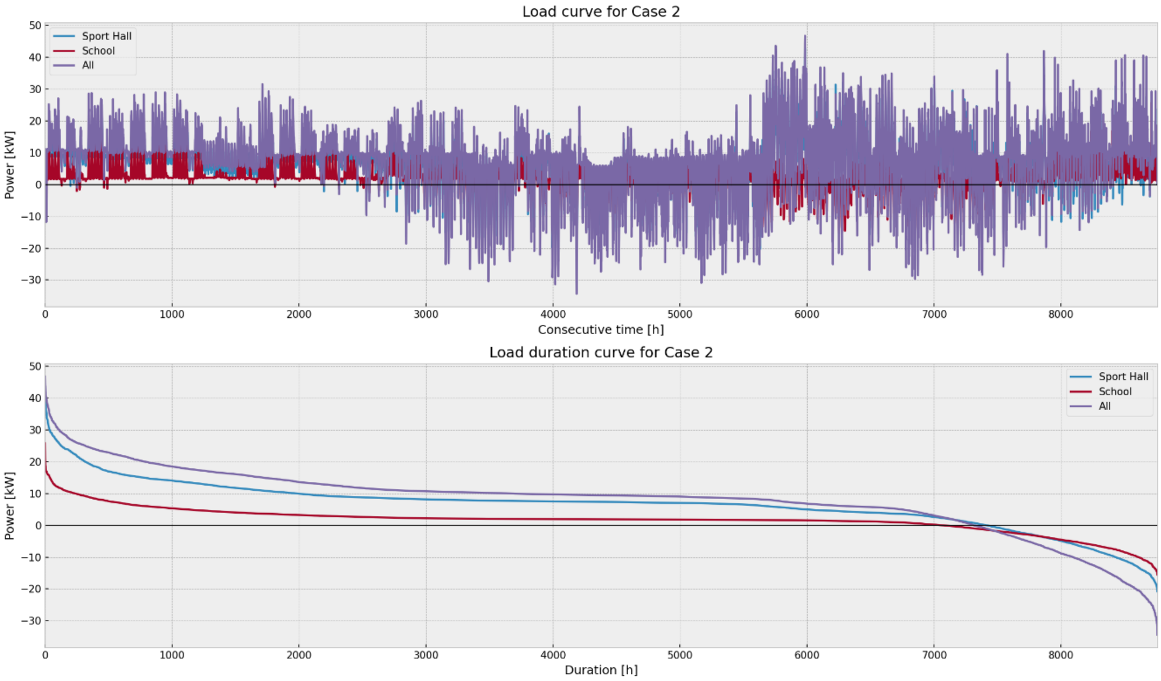


Figure 37 The load curves and load duration curves for the measuring points in Use Case 2.

Last graph (Figure 38) presents the usage in waste water treatment plant – Use Case 3.

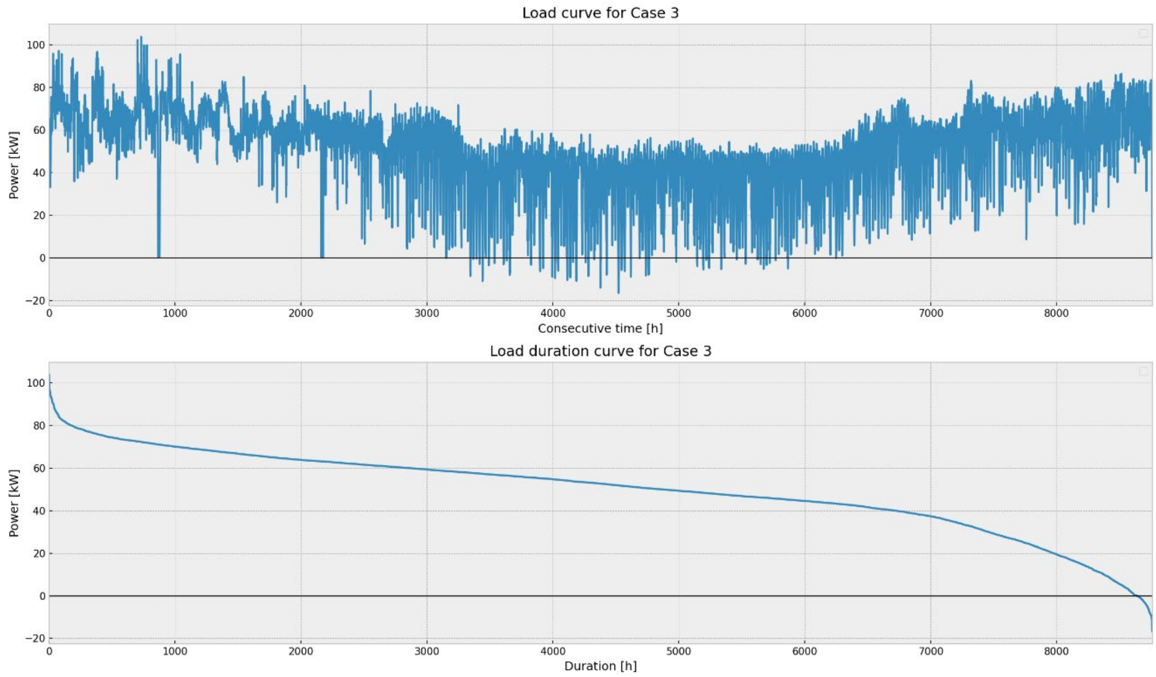


Figure 38 The load curves and load duration curves for the measuring points in Use Case 3.

7.2 Analysis – Collective measuring points and Energy clusters

Based on data gathered, various technical scenarios of cooperation between selected installations are proposed in order to facilitate future discussions with stakeholders leading to the creation of a pilot energy community in Przywidz. Energy clusters are legal entities, but they do not get any real profits or discounts from their status, although the potential is in considering different objects and installations as one.

Polish system for photovoltaic installation is in the mayor transition from net metering to net billing – so there are already situations where in one area part of the installation has net metering and other part net billing. In net metering amount of energy injected into electric grid can be later settled with amount taken with ratio 0.7 or 0.8. In net billing amount of energy injected into electric grid can be later settled with amount taken with respective sell/buy prices, often below 0.7 ratio and lower. As at times some neighbouring measurement points take energy, and some measurement point inject energy into grid there is potential to save money if they are treated as ‘collective measuring points’. Legal aspects of this scenario are not clear in current Polish conditions. This aspects are to be analysed further in the project. Below this potential is evaluated for different ‘collective’ groups.

Table 9 Summary of the scenarios for collective users.

			Standard case		Collective user
No of scenario	Use Case	Group	Usage [kWh]	Injection to the grid [kWh]	Injection to the grid [kWh]
1	**UC 1**	PV users	157156	101039	78058
2	**UC 1**	All users	318916	101039	44347
3	**UC 2**	Sport hall + school	122298	16781	14916
4	**UC 1+2**	All users UC1 and UC2	441213	117820	56181
5	**UC 1+2+3**	All users UC 1+2+3	936046	118319	37876
6	**UC 1+2+TH**	All users in case 1, case 2 and Town Hall	485521	127937	64698
7	**UC 1+2+3+TH**	All users UC 1+2+3+ Town Hall	980353	128436	44530
8	**Municipal**	All users in case 2, case 3, Town Hall, Pump Station and Kindergarten	1088095	31095	10490

7.3 Analysis – 'Energy cooperative'

The cooperative is a return (an attempt to return) to what net-mettering offered (security, certainty, price stability), but with potentially higher investment costs, which can be offset by the economy of scale (larger, joint installations). One of the requirements for establishing energy cooperative is generating at least 70% of energy used annually (another threshold for better prices is 100%). Since data form photovoltaic inverters in individual households in Case 1 cannot be obtained, it was calculated with assumption of 30% self-consumption. Below is example calculation for household no. 1:

- Electricity injected into grid: 4737 kWh
- Electricity consumed form grid: 4722 kWh
- Electricity generated: 4737 / 0,7 = 6767 kWh
- Electricity used: 4722 + 4737 * (1 / 0,7 - 1) = 6752 kWh

Since generation data from Pump Station cannot be obtained it was assumed to be 17 MWh (16,74kWp PV installation).

All annual sums are presented in Table 9. The detailed cases are presented below.

Case 1

PV users in case 1 excluding Pump Station and Kindergarten are considered and they generate 88% of their energy usage (generation: 139 MWh and usage: 157 MWh). They generate sufficiently to be considered an energy cooperative.

If all of the PV users in Use Case 1 are considered including Pump Station and Kindergarten then the cooperative is not reaching required 70% threshold. To qualify a 24 MWh more would need to be generated (generation: 161 MWh and usage: 265 MWh).

All users in Case 1 use 427 MWh, so 138 MWh more would need to be generated to qualify for energy community. 138 MWh could be generated by approx. 71kW wind turbine in good wind conditions or approx. 125kWp photovoltaic system in with good Insolation.

Case 1+2

To qualify all users in case 1 and case 2 under 70% threshold, 172 MWh more would need to be generated (generation: 212 MWh and usage: 549 MWh).

The graphical representation of the cases is presented in Figure 39.

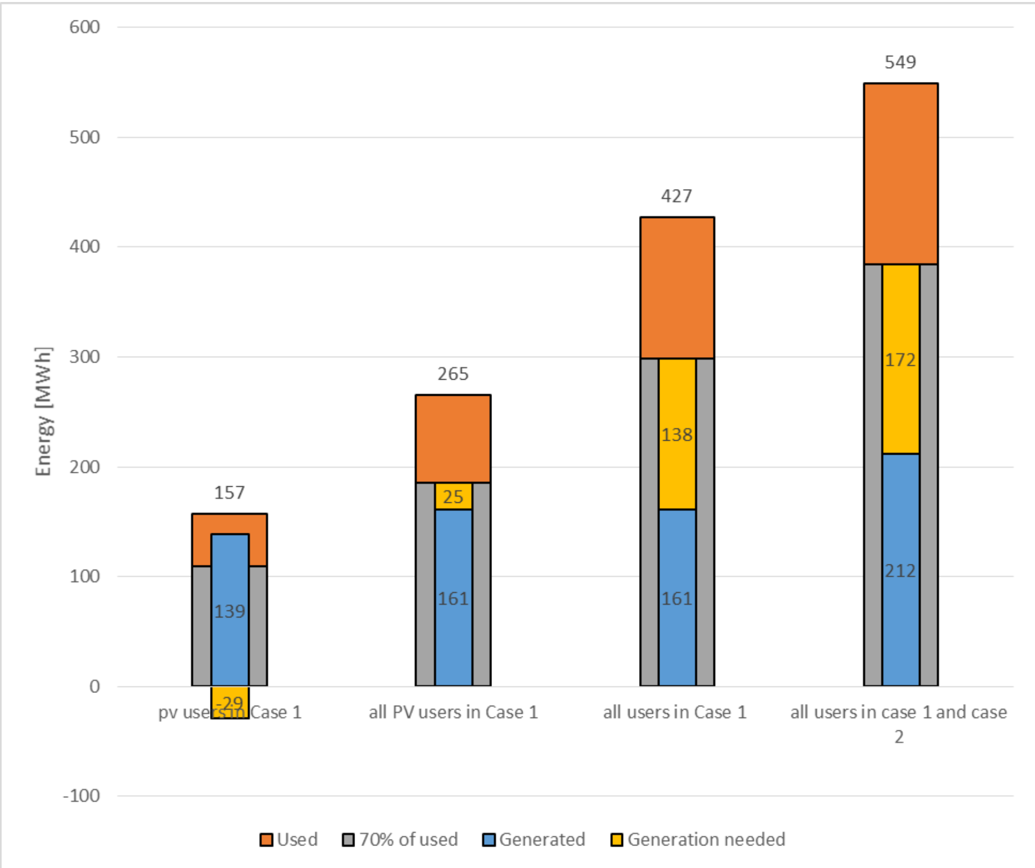


Figure 39 The graphical representation of the potential of energy cooperative for scenarios in Use Case 1 and 2.

To calculate the financial outcome and potential benefits, at the moment, a number of assumptions has to be made, regarding:

- Lack of data regarding the prices for selling energy in net-billing schema for half a year (such prices started to be defined in the middle of 2022), the changeability of those prices is not yet known due to short data sample and very unusual situation on the energy market in 2022.
- Transition from net-metering to net-billing – there is no information how many prosumers are in which system.
- Volatility of energy purchase prices in 2022.

- Changeability of regulations (changes in taxes, introduction of limits, special prices for different types of users, e.g. the special prices up to a limit of 2000 kWh for households).
- Different tariffs and different contracts for users, prosumers, households and companies – generalization would introduce large error and each case should be analyzed separately.
- Different profiles of usage and production – for good analysis detailed data regarding hourly or 15-minutes profiles should be available.

8 Electricity energy storage

8.1 Business models – Behind-the-meter applications

From a customer point of view, the most straightforward implementation of an Energy Storage System (ESS) is to install a battery at their own premises. It operates at the customer side of an energy meter and serves a single point of coupling to the grid [32]. Similarly, local communities can install an Energy Storage System in private and municipal buildings.

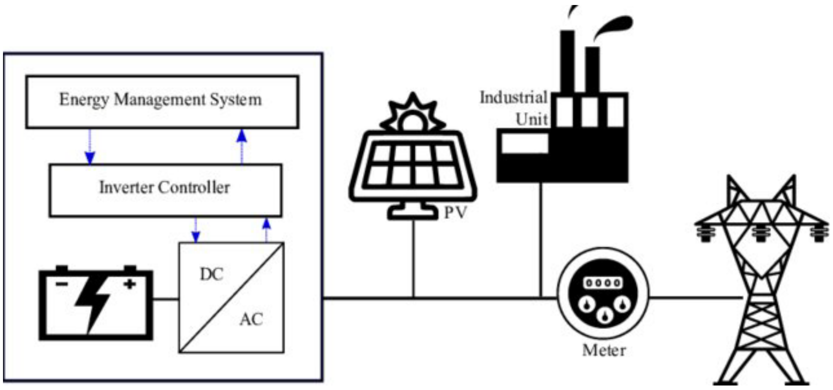


Figure 40 Behind the meter battery scheme [32].

Energy Storage Systems can be used to implement the following functions, which connect to potential business models:

- Increased RES self-consumption. The battery is charged using the surplus of photovoltaic generation and discharged to supply loads when no power is generated. The profitability of such a model is dependent on the prices at which energy is bought and sold (both can vary in time), as well as on the consumer profiles and on the local RES type and power.
- Time-of-use strategy that charges battery in off-peak tariff and uses stored energy to supply loads during peak hours. This mode is applicable for both consumers and prosumers, but of course requires a tariff with peak and off-peak differences.
- Backup/unterruptible power supply. The Energy Storage System can serve as a power source in case of the grid outages and disturbances. Such an installation can replace the investment in UPS and/or backup gensets.
- Demand Side Response. An Energy Storage System is a perfectly flexible asset to shift individual energy usage by 1-4 hours. This allows the owner to participate in DSR schemes, allowing customers to achieve additional remuneration.

These schemes are widely used around the globe in many different applications including households, municipal buildings, commerce and industry. These models are as well viable in Poland. The Demand Side

Response market is also available, however at present it is focused on large objects with a large potential to reduce power on demand.

8.2 Business models – Neighbourhood batteries

The business models mentioned above can also be realised with larger batteries that are owned and operated by communities. Neighbourhood batteries (or community batteries) are an energy storage model with the potential to provide many benefits to consumers, communities and the electricity system [33]. The idea is to install a bigger energy storage unit for larger group of consumers and/or prosumers to maximise profitability and serve the whole collective. With the larger power and capacity, some of business models – such as Demand Side Response – is easier and more effective. In addition, such a battery can serve technical purposes, e.g. voltage regulation, and in consequence it can increase RES penetration potential. The ownership of the batteries can vary:

- electricity distribution businesses
- community energy groups,
- electricity retailers,
- aggregators,
- private inverstors, etc.

The neighbourhood Energy Storage system concept is however in a pilot phase. Functionality and business models for such systems are much more complex than for individual batteries and have to be proven practically [34].

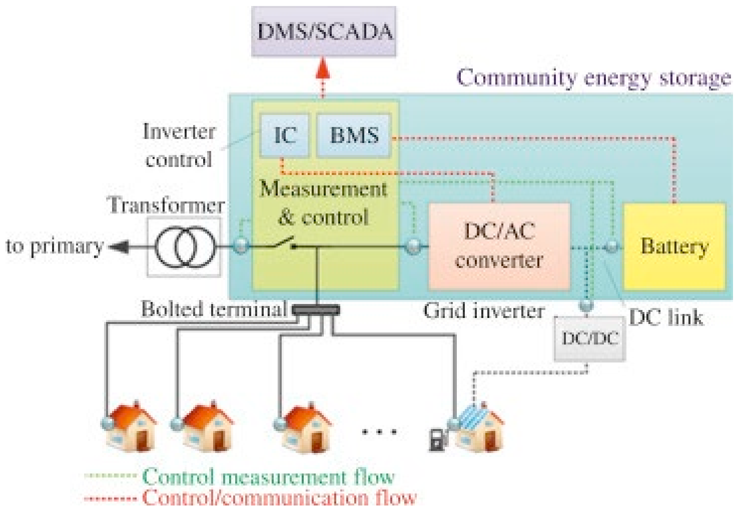


Figure 41 Neighbourhood battery scheme [34].

Few neighbourhood battery projects have been deployed in EU, as reported in the STORY project report [35]. The report indicates that community batteries have the advantage of enable the integration of various storage technologies, which would not be feasible in the case of single household.

Such pilot systems are also developed in Australia, in the state of Victoria [33]. The size of neighbourhood batteries ranges from 100 kW to 5 MW. The community installed a pilot project in Fitzroy North in June 2022. The Yarra Energy Foundation received $800,000 from the Neighbourhood Battery Initiative for a 110kW/284kWh battery system. Australia's ABC News reports that households taking part in the neighbourhood battery pilots saved around AUS$81,000 on electricity costs over the five years of the trial.

They also consumed 85% less energy from Australia's electricity grid at peak times [36]. The pilot project is reported in [37].

8.3 Applications in Przywidz

The Polish demo site in Przywidz expects to test the operation of the Energy Storage System operating in few locations and demonstrate possible applications. Task 6.5 aims to implement:

- Stationary Energy Storage System using Vanadium Redox Flow technology (VRFB). A container with two VRFB modules having in total 20kW and 96kWh will be installed in the second Use Case (Arena Przywidz).
- Mobile Energy Storage System using lithium-iron-phosphate technology. The mobile battery is a 25 kW, 64 kWh all-in-one energy storage system that can be moved around using a dedicated trailer and reconnected between different points in the grid. The mobility will allow to conduct short-term demonstrations at different locations.

Figure 42 Mobile energy storage: all-in-one cabinet and dedicated transport trailer.

Municipality buildings will be equipped with a behind-the-meter Energy Storage System. The demos of the mobile energy storage system are basically focused on energy balancing applications; the last location will demonstrate technical possibilities of the Energy Storage System operating as neighbourhood battery.

Mobile Energy Storage System location 1: Public kindergarten

The kindergarten building is equipped with a 12,7kWp photovoltaic source and a heat pump. Energy balancing will be demonstrated with the aim to minimize energy flow (maximize self-consumption) and energy cost (minimize consumption in peak hours). The annual consumption is around 42 MWh

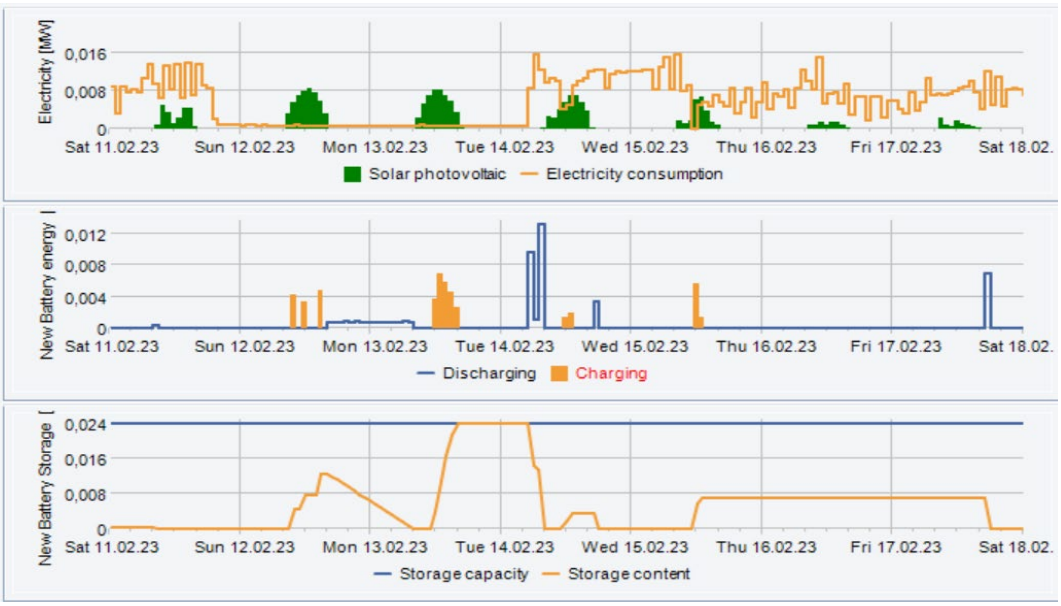
Preliminary studies were conducted in form of a techno-economical simulation. Customer profiles recorded by means of the DSO's energy meter were provided as an input. Below, the results of the annual operation are shown, considering two price profiles: regulated (as e.g. for a municipality prosumer) and commercial.

1. Municipality prosumer: the energy price is regulated by the government and set for 2023 at the fixed level of 785 PLN/MWh. In the net-metering system (which applies to prosumers connected before 04.2022), surplus energy is exported to the grid and 80% of its amount can be imported within one year period (the model assumes that customer sells surplus energy at 80% of the purchase price).

Table 10 Simulation results of municipal prosumer with regulated prices.

	Consumption only	With PV	With PV and 30kWh ESS	With PV and 64kWh ESS
Energy import [MWh]	42	36,5	32,9	31,5
Energy export [MWh]	-	9,4	4,9	3,3
Energy stored [MWh]	-		3,6	4,9
Self-consumption rate	-	37%	67%	78%
Share of RES	-	13%	22%	25%
Energy buy cost [PLN]	32 977	28 627	25 807	24 746
Energy sell profit [PLN]	-	5 890	3 104	2 057
Net cash [PLN]	-32 977	-22 737	-22 702	-22 689

a) Winter Profile



b) Summer Profile

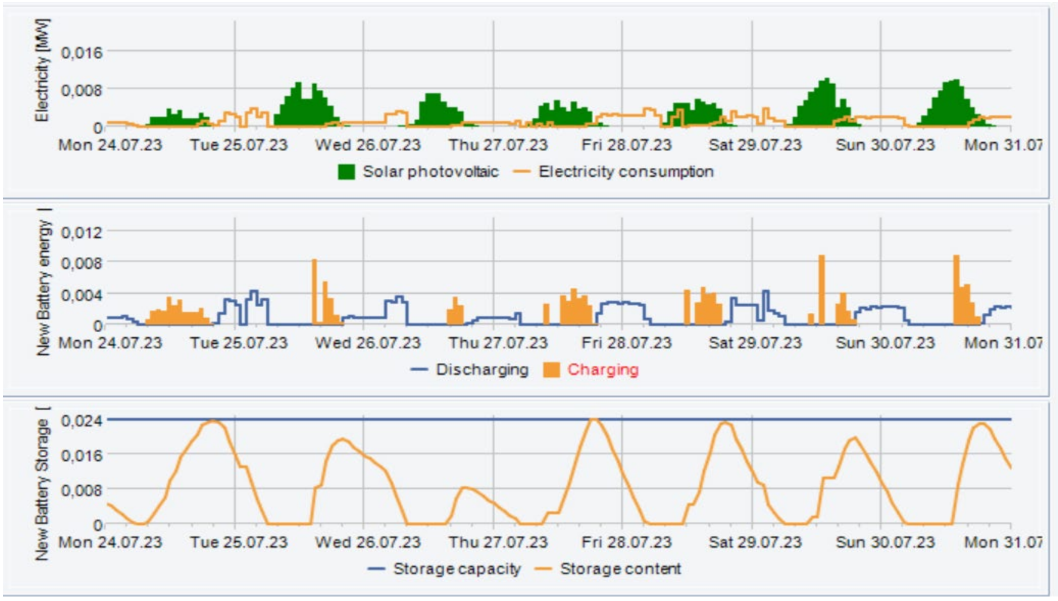


Figure 43 Power profiles of kindergarten operating with PV and 30kWh ESS with regulated prices: a) winter, b) summer.

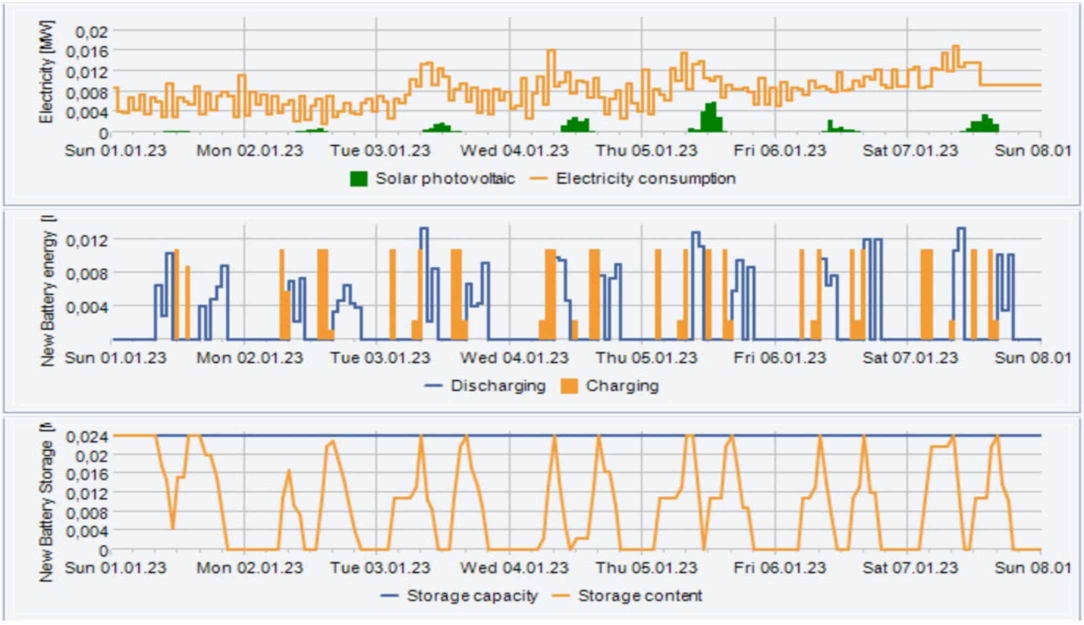
Analysis of the simulation results lead to the conclusion that investing in behind-the-meter energy storage is not cost-effective for customers with regulated prices. First of all, in the net-metering system, prosumers can use electricity grid as an Energy Storage System with 80% efficiency. Second of all, the flat price profile does not enable time-of-use strategies to reduce the energy bill. The only remaining advantages for the customer are increased self-consumption and increased reliability thanks to backup power. These aspects will be verified using the real world installation and data.

2. Free market customer: the energy prices are set to reflect a commercial customer. The current retail prices are set at 3091 PLN/MWh in peak hours and 1973 PLN/MWh in off-peak hours [38]. In the simulation, surplus energy is sold with an average price for the mass market of 566 PLN/MWh [39].

Table 11 Simulation results of municipal prosumer with market prices.

	Consumption only	With PV	With PV and 30kWh ESS	With PV and 64kWh ESS
Energy import [MWh]	42	36,4	34	33,2
Energy export [MWh]	-	9,6	5,1	3,4
Energy stored [MWh]	-	-	8,9	12,8
Self-consumption rate	-	37%	66%	78%
Share of RES	-	13%	22%	25%
Energy cost (peak) [PLN]	38 899	34 281	10 570	693
Energy cost (off-peak) [PLN]	67 515	58 121	68 132	72 434
Energy sell profit [PLN]	-	5 419	2 891	1 918
Net cash [PLN]	-106 413	-86 984	-78 702	-73 434

a) Winter Profile



b) Summer Profile

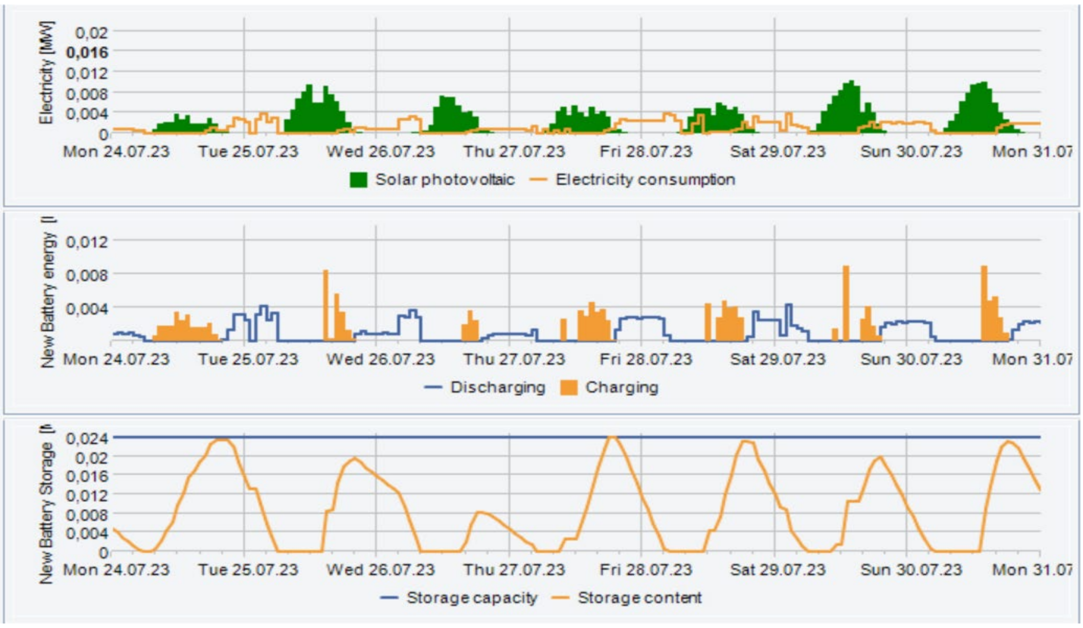


Figure 44 Power profiles of kindergarten operating with PV and 30kWh ESS with market prices: a) winter, b) summer.

The results clearly show the difference in battery operation when the energy process is dynamic. The Energy Storage System significantly reduces energy consumption in peak hours. The winter profiles show clearly that the battery, when it is not used for photovoltaic balancing, serves for time-of-use purposes. With two off-peak periods in the selected tariff, the battery does two cycles per day. As a result, Energy Storage System operation can reduce energy bill significantly. The price profiles do not influence factors such as RES self-consumption and the share of RES in energy usage: in both cases ESS can double the amount of locally used generated solar energy.

Mobile Energy Storage System location 2: Sports hall

The power of photovoltaics installed on the sport hall 'Arena Przywidz' and on the school building (integrated with sports hall) are respectively 39.99 kWp and 26.04 kWp. The SERENE project will deliver two electric vehicle chargers and heat pumps that will be integrated in the system. Arena Przywidz and the school demonstrate the role of an energy storage unit in such a building complex. Initially, the Energy Storage System will only contain a VRFB, in a later stage it will be augmented with a mobile battery to form a hybrid energy storage system. The Sports hall use-case will also attempt to demonstrate intentional and automatic operation in island mode.

The whole object will form a microgrid that is governed by an Energy Management System. The use-case will show that, thanks to a coordinated control of the assets, the system will gain flexibility in terms of energy shifting. The aim of the Energy Management System is to increase self-consumption from the photovoltaic installation and reduce load in peak hours to cut down on energy cost in the municipal building. Additionally, the project will search for synergies with Demand Side Response related projects in which the partner Energa Operator is involved.

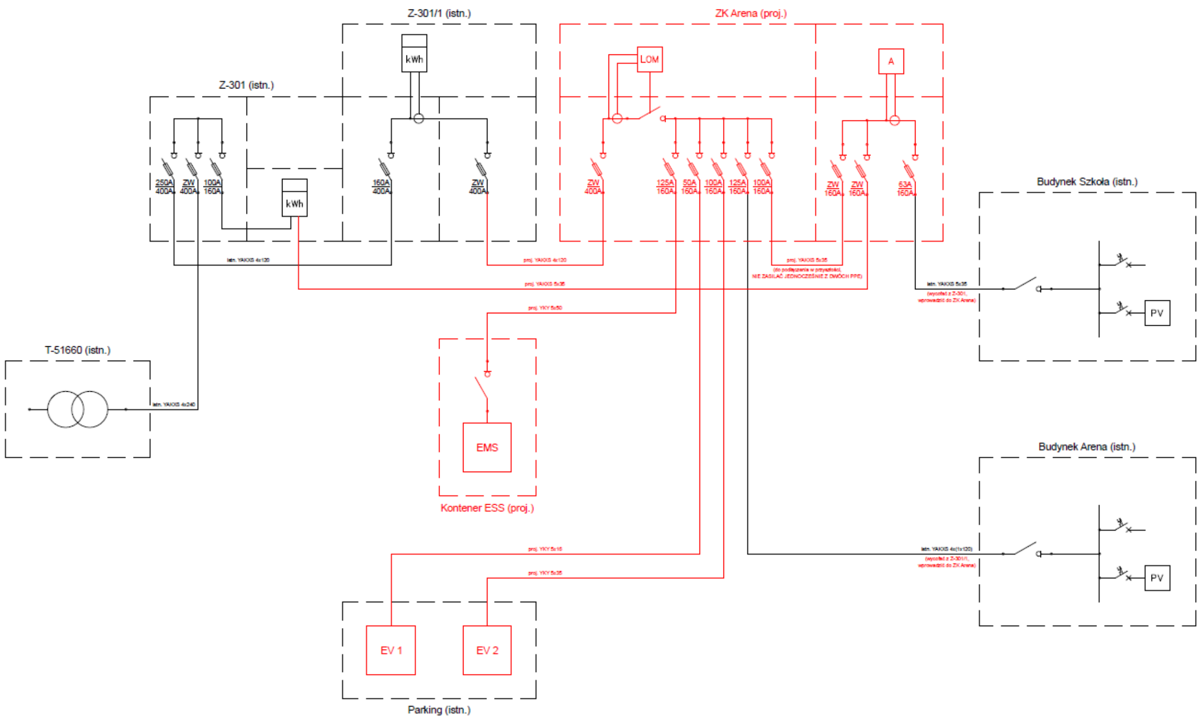


Figure 45 Single line diagram of Arena Przywidz and school building with planned ESS and EV chargers.

Figure 46 Vanadium Redox Flow Battery container sited next to Arena Przywidz.

Mobile Energy Storage System location 3: Pump station

The pump station it is located near a transformer substation that serves the district of use-case 1. An Energy Storage System installed at this point will be capable of demonstrating the functionality of a neighbourhood battery. The intention is to integrate substation meters and power quality measurements with the battery control system. The Energy Storage System should then be able to influence power quality at low voltage terminals by providing services such as peak shaving, reactive power compensation and voltage support. These are strictly technical features that create services for the DSO. Potential business models, which include the installation of Energy Storage System by the DSO and the provision of services by a community Energy Storage System, will be examined.

9 Flexibility services – DSR – Use Case 3

Demand Side Management is a general term for all activities aimed at adjusting the demand side of electric systems to improve its operation [40]. Demand side response (DSR) is the service of reducing the customer's energy usage for some defined time as a response to some signal or incentive. In Poland, the DSR services are active from 2017 and were, in the beginning, solely organized by the Polish Energy Networks - PSE (Polskie Sieci Energetyczne) [41]. PSE was organising tenders and programmes for DSR contracts, which were successful - the initial contracts for reduction were for 361 MW in summer time and 315 MW in winter time. The programmes evolved till, on 1st of January 2021, the Polish energy market faced a revolution – many regulations changed in different areas, the capacity market was started, DSR services were redefined and stopped being dependent on PSE. On 28th of December 2020, PSE S.A. started public tender to appoint DSR services controllers; 6 companies were chosen: CMC Poland Sp. z o.o., Enel X Polska Sp. z o.o., Enspirion Sp. z o.o., Lerta S.A., Polenergia Obrót S.A. and Tauron Sprzedaż Sp. z o.o. [42].

The conditions for DSR services are defined by each DSR service controller; for the analysis of the feasibility of such solution the data from Enspirion Sp. Z o.o. was obtained. This provider so far only considered contracts for a minimum of 200 kW reduction of power, but is now actively researching possibilities to work with larger groups of smaller units to manage distributed DSR services. The standard conditions for the DSR contracts are:

- The average amount of remuneration for readiness to implement DSR for 2024 (2023 is already closed) is PLN 190,000 net / MW per year.

- The maximum number of hours of a single reduction requests is 4 hours, minimum is 1 hour.
- The maximum number of reduction requests is 50 per year, on average one can expect 2-4 request for an hour per year.
- There are penalties for not responding properly to the reduction request and also a possibility to reimburse additional response over the limit.

Enspirion Sp. z o.o. requests reductions only on business days, between 7 am and 10 pm (the last call for 1 hour is possible at 9 pm). Information about the request for reduction comes minimum 7.5 hours before the reduction time. The base level for the reduction is the average of the 3 hours before the reduction start-time to calibrate the normal operation profile. Then, during the reduction, the average of the entire reduction is calculated, the usage is subtracted from the profile, and the result is the reduction that was actually made. The performed reduction level should of course be at least equal to the capacity obligation.

It is allowed to use some type of generator to help with reduction and increase the possible reduction capacity. It is even possible to give energy to the grid during reduction, then the facility is considered a Demand Reduction Unit with internal generation. One important aspect is that the generator used for the reduction has to emit less than 550 g of CO_2 per kWh (photovoltaic installation is considered to be zero-emission for this).

Presently, the DSR services are not possible to be implemented in Use Case 1, as the households do not have enough reduction potential to be considered for the service. The municipal buildings in Use Case 1 and 2 have to fulfill their primary function working at the lowest costs possible – the school cannot change its usage upon request.

However, the water treatment plant in Use Case 3 can be potentially considered as a part of DSR services. The initial, estimated, possible amount of reduction for the whole facility is 0.25 MW – it is the sum of all devices that can be safely switched off for the 4-hour window and the power given by the diesel generator that is supposed to provide electricity in case of power shortage. Such power would give the municipality 47500 PLN/year. Unfortunately, the existing generator emits around 610 g CO_2 per kWh, which exceeds the limit. Removing the power of the generator would decrease the reduction power by half, which makes it not feasible for the current contract conditions with the Enspirion Sp. z o.o.

At present, it seems that the Use Case 3 cannot serve as a DSR service provider. However, Enspirion Sp. z o.o. is working on lowering the required reduction capabilities for a DSR service provider in the context of automating the process to more easily achieve a reduction. In addition, there is a potential of installing additional sources at the site of Use Case 3, not only from a technical perspective, but there also is a willingness to do so. As such, it is still valuable to consider scenarios for DSR services for Use Case 3. This will be continued to be considered and modelled within the SERENE project.

10 Conclusions and Outlook

The study of the technical, socio-economic-institutional schemes as well as the detailed considerations for each of the 3 demo cases analysed in Przywidz, provide interesting insights in how seemingly simple concepts can differ between member states. This is due to differences in legislation, but also due to social and technical differences and highlights some challenges ahead.

In general, it is clear that the bottom-up movement, where the idea of a community as a group of smaller consumers, producers and prosumers that together act as a single bigger player on the energy market, has the potential to be economically beneficial while speeding up the process of energy transition and decarbonisation.

Specifically looking at the Polish reality, it appears that the current legislation, which only allows two types of energy communities is behind other partners' countries. However, it is not an easy transition for legislators, with the safety and quality of the energy supply at stake. It is clear that many changes have been made in a short time, and many more can be expected as discussions are ongoing and momentum is gained.

The Polish people are aware of the need for the energy transition, not only for environmental reasons but also for economical reasons. The younger generation clearly cares about the climate and, while at this point they are not the driving force, their voices are getting heard more. The SERENE project can support their calls to help increase awareness and to provide examples: the different Use Cases are quite visible in Przywidz, particularly the changes at the school, and this not only gets attention from the local population but also does not go unnoticed in wider media.

The SERENE project aims to create a community that will be open to implement solutions when they become available and search for new opportunities to support the energy transition and decarbonisation.

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